11143

BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOLUME 12

JOSEPH STANLEY-BROWN, *Editor*

ROCHESTER
PUBLISHED BY THE SOCIETY
1901

COUNCIL FOR 1901

CHARLES D. WALCOTT, *President*

N. H. WINCHELL, } *Vice-Presidents*
S. F. EMMONS, }

H. L. FAIRCHILD, *Secretary*

I. C. WHITE, *Treasurer*

J. STANLEY-BROWN, *Editor*

Class of 1903

SAMUEL CALVIN

A. P. COLEMAN

Class of 1902

W. B. CLARK

A. C. LAWSON

Class of 1901

W. M. DAVIS

J. A. HOLMES

PRINTERS
JUDD & DETWEILER, WASHINGTON, D. C.

ENGRAVERS
THE MAURICE JOYCE ENGRAVING COMPANY, WASHINGTON, D. C.

CONTENTS

ILLUSTRATIONS

Plates

Figures

(45 plates, 28 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetra, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date twelve volumes have been published and an index to the first ten volumes.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America, not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending on the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, Rochester, New York.

Description of the published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	662 + xiv	23	63	4.50
Vol. 3, 1891	541 + xi	17	72	4.00
Vol. 4, 1892	458 + xi	10	55	3.50
Vol. 5, 1893	665 + xii	21	43	4.00
Vol. 6, 1894	528 + x	27	40	4.00
Vol. 7, 1895	558 + x	24	61	4.00
Vol. 8, 1896	446 + x	51	29	4.00
Vol. 9, 1897	460 + x	29	49	4.00
Vol. 10, 1898	534 + xii	54	83	4.00
Index to first ten volumes	209	..	..	2.25
Vol. 11, 1899	651 + xii	58	37	4.50
Vol. 12, 1900	538 + xii	45	28	4.00

Brochures of Volume 12

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Twelfth Summer Meeting, held at New York city June 28, 1900. H. L. Fairchild, *Secretary*.	1- 12	....	....	$0.15	$0.30
Pleistocene ice and river erosion in the Saint Croix valley of Minnesota and Wisconsin. Warren Upham	13- 24	....	....	.30	.60
Giants' kettles eroded by moulin torrents. Warren Upham	25- 44	1	....		

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Volcanic phenomena on Hawaii. C. H. Hitchcock	45– 56	2-5	1	$0.50	$1.00
Geological record of the Rocky Mountain region in Canada. G. M. Dawson.	57– 92	....	....	.35	.70
Weathering of granitic rocks of Georgia. T. L. Watson	93–108	6–11	....	.50	1.00
Glacial lakes of Minnesota. N. H. Winchell	109–128	12	....	.25	.50
Marine and freshwater beaches of Ontario. A. P. Coleman	129–146	....	1–2	.20	.40
Paleozoic limestone of Kittatinny valley, New Jersey. H. B. Kümmel and S. Weller	147–164	....	1	.20	.40
Sand crystals and their relation to certain concretionary forms. E. H. Barbour	165–172	13–18	1–2	.45	.90
A depositional measure of unconformity. C. R. Keyes	173–196	19	1–2	.30	.60
Wisconsin shore of lake Superior. G. L. Collie	197–216	....	1–2	.20	.40
Origin and structure of the Basin ranges. J. E. Spurr	217–270	20–25	....	1.25	2.50
Broad valleys of the Cordilleras. N. S. Shaler	271–300	....	....	.25	.50
Knoydart formation of Nova Scotia. H. M. Ami	301–312	26	1	.25	.50
Keweenawan area of eastern Minnesota. C. W. Hall	313–342	27–28	1–3	1.00	2.00
Keewatin area of eastern and central Minnesota. C. W. Hall	343–376	29–32	1–3		
Geology of Rigaud mountain, Canada. O. E. Le Roy	377–394	33–34	1–2	.25	.50
Silurian and Devonian limestones of Tennessee and Kentucky. A. F. Foerste.	395–444	35–41	1–8	.70	1.40
Proceedings of the Thirteenth Annual Meeting, held at Albany, New York, December 27, 28, and 29, 1900, including Proceedings of the Second Annual Meeting of the Cordilleran Section, held at San Francisco, December 28 and 29, 1900. H. L. Fairchild, *Secretary*	445–538	42–45	1	1.50	3.00

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a Memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 12 have been issued:

Editions uniform with the Brochures of the Society

Pages	13- 24,	30 copies.	November	30, 1900.
"	25- 44, plate 1;	30 "	December	6, 1900.
"	45- 56, plates 2- 5;	200 "	"	21, 1900.
"	57- 92,	330 "	February	25, 1901.
"	93-108, plates 6-11;	80 "	"	26, 1901.
"	109-128, plate 12;	30 "	"	28, 1901.
"	129-146,	30 "	March	25, 1901.
"	147-164,	100 "	April	13, 1901.
"	165-172, plates 13-18;	305 "	"	16, 1901.
"	173-196, plate 19;	30 "	"	18, 1901.
"	197-216,	55 "	"	30, 1901.
"	217-270, plates 20-25;	100 "	"	30, 1901.
"	271-300,	80 "	June	17, 1901.
"	301-312, plate 26;	130 "	August	16, 1901.
"	313-342, plates 27-28;	230 "	"	31, 1901.
"	343-376, plates 29-32;	230 "	"	31, 1901.
"	377-394, plates 33-34;	230 "	September	4, 1901.
"	395-444, plates 35-41;	130 "	October	31, 1901.

*Special Editions**

Pages	2- 4,†	30 copies.	November	30, 1900.
"	4- 9,	150 "	"	30, 1900.
"	9- 10,	80 "	"	30, 1900.
"	10- 11,	30 "	"	30, 1900.
Page	11,	30 "	"	30, 1900.
Pages	447-453,	30 "	"	27, 1901.
"	454-455,	30 "	"	27, 1901.
"	455-461, plates 42-43;	30 "	"	27, 1901.
Page	461,	30 "	"	27, 1901.
"	462,	30 "	"	27, 1901.

* Bearing the imprint [From Bull. Geol. Soc. Am., Vol. 12, 1900].

† Fractional pages are sometimes included.

Pages 462–463,	30 copies,	November 27, 1901.
Page 463,	130 "	" 27, 1901.
" 464,	30 "	" 27, 1901.
Pages 465–471,	30 "	" 27, 1901.
Page 471,	30 "	" 27, 1901.
Pages 472–473,	30 "	" 27, 1901.
" 473–477,	105 "	" 27, 1901.
" 478–479,	30 "	" 27, 1901.
" 480–483, plates 44–45;	30 "	" 27, 1901.
Page 483,	30 "	" 27, 1901.
Pages 483–485,	100 "	" 27, 1901.
Page 485,	30 "	" 27, 1901.
Pages 486–490,	80 "	" 27, 1901.
" 490–491,	155 "	" 27, 1901.
Page 493,	30 "	" 27, 1901.
" 494,	30 "	" 27, 1901.
Pages 495–596,	30 "	" 27, 1901.
" 496–497,	30 "	" 27, 1901.
Page 498,	30 "	" 27, 1901.
Pages 498–499,	30 "	" 27, 1901.
" 499–500,	30 "	" 27, 1901.
" 500–501,	30 "	" 27, 1901.
Page 501,	30 "	" 27, 1901.
Pages 501–502,	30 "	" 27, 1901.
" 503–512,	30 "	" 27, 1901.
" 513–522,	30 "	" 27, 1901.

CORRECTIONS AND INSERTIONS

All contributors to volume 12 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 149, line 16 from top; *for* "Wolf" *read* Wolff
" 150, " 14 " " ; *for* "Wlof" *read* Wolff
" 151, " 18 " bottom; *for* "Wolf" *read* Wolff
" 162, " 10 " top; *for* "limestone" *read* limestones
" 319, " 14 " bottom; *insert* not between "must" and "pass"
" 327, " 11 " top; *for* "lying" *read* lies
" 342, " 5 " bottom; *omit* "and across the Douglas County fault line"
" 362, lines 11 and 12 from top; *for* "plate 31, figures 1 and 2," *read* plate 31, figure 1 and plate 32, figure 1

Page 362, line 14 from bottom; *for* "plate 31, figure 2," *read* plate 32, figure 1
" 376, *for* description of plate 31, figure 2, *read* that of plate 32, figure 1, and *vice versa*

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 1-12 NOVEMBER 30, 1900

PROCEEDINGS OF THE TWELFTH SUMMER MEETING, HELD AT NEW YORK CITY, JUNE 26, 1900

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF TUESDAY, JUNE 26

The Society was called to order at 11.45 o'clock a m, in room 401, Schermerhorn Hall, Columbia University. The President, Dr George M. Dawson, occupied the chair throughout the meeting.

ELECTION OF FELLOWS

The Secretary announced that the three candidates for fellowship had received a nearly unanimous vote of the ballots transmitted, and that they were elected, as follows:

Fellows Elected

LEONIDAS CHALMERS GLENN, Ph. D., Columbia, South Carolina. Professor of Geology, South Carolina College.

THOMAS LEONARD WATSON, Ph. D., Atlanta, Georgia. Assistant State Geologist, Georgia State Geological Survey.

STUART WELLER, B S., Walker Museum, University of Chicago. Instructor in University of Chicago.

The announcement was also made by the Secretary that the next Winter meeting would probably be held at Albany, New York.

The reading of papers was declared in order. The first paper of the program was

GEOLOGY OF THE SILVER PEAK RANGE, NEVADA

BY H. W. TURNER

In absence of the author the next paper was read by J. F. Kemp:

NATIVE COPPER NEAR ENID, OKLAHOMA

BY ERASMUS HAWORTH AND JOHN BENNETT

Contents

Discovery and Location of the Copper

About two years ago an unknown person sent to the University of Kansas for identification a sample of material which proved to be unusually interesting. It consisted mainly of a piece of the well known Red Beds clay shale so common in southern Kansas and northern Oklahoma, but in small crevices or fissures within the mass were numerous thin sheets of metallic copper, from a half inch to two inches in width, so thin that they could be rolled between thumb and finger almost as readily as tinfoil.

For two years persistent efforts were made to learn the location of this find and information regarding it. Last autumn these efforts were successful. The location is about 18 miles northwest from Enid, on the farm of Mr O. P. Barnes, near the northwest part of Garfield county, Oklahoma.

Oklahoma was opened for homesteading as agricultural lands, and Mr Barnes and neighbors feared that the finding of this native copper would cause the land to be classed as mining land and thereby interfere with their homesteads, and hence the difficulty in learning details concerning the discovery.

The farm of Mr Barnes occupies a portion of the watershed between the Cimarron river on the south and a tributary of the Arkansas on the north. It is well within the Red Beds area, but just where on the vertical scale is not yet determined.

Section of Well in which Discovery was Made

The copper was found in a six-inch stratum at the bottom of the well 32 feet

deep, dug to obtain water for domestic use. A section of the well, as obtained by Bennett, is as follows, numbering from the top:

1. Ten feet of alluvial material.
2. Five feet of dark red clay shale.
3. Six inches of light colored clay shale.
4. Two feet of light red clay shale.
5. Three feet six inches of mottled dark red and light clay shale.
6. One foot ten inches of red clay shale.
7. One foot three inches of light clay shale.
8. One foot six inches of dark red clay shale.
9. Five feet three inches of mottled red and light clay shale with red greatly predominating.
10. Six inches of mottled red and light clay shale, the copper-bearer.
11. A hole was dug in the bottom of the well about two feet deeper into the red clay shale, but no more copper was found.

Nature of the Copper Deposit

The six-inch copper-bearing horizon is not materially different from that above and below excepting that the little fissures within it are filled with the metallic copper. From the small exposure in the well it seems that near the middle of the layer the copper films approach a horizontal position, but both above and below they are inclined at almost every angle, showing a total lack of regularity. From an examination of the surrounding country it was learned that the bedding planes of the clay shales are practically horizontal. Wherever good exposures were found many small fracture seams were noticed, as is so common in the Red beds elsewhere—seams likely produced by the contraction of the sediments upon drying. The copper films occupy these fissures, and therefore have been deposited since the fissures were formed.

It is reported that copper was also found in a well about a mile distant from the one described, but this was not examined. Careful search along neighboring canyon walls failed to reveal any copper; but the search was not sufficiently extended to have an important bearing on the question of extent of the deposit. Further developments will be awaited with interest.

Origin of the Copper

Nature of the Red Beds

It is interesting to inquire into the methods by which this native copper may have originated. With our limited knowledge of the environments, it must be admitted that any theorizing on the subject may lead to error. It is generally admitted that the Red beds are a mass of clay shales, sometimes quite arenaceous, accumulated beneath ocean water so strongly concentrated that no life could exist within it, and that therefore they are highly colored with red iron oxide.

The copper-bearing stratum shows no sign of having been reduced by surface agencies. Under such circumstances it would seem that organic matter could have had no part in the reduction of the copper. If the copper were held in solution as a sulphate it may have been associated with ferrous sulphate and a trace of free sulphuric acid, products generally formed by the weathering of copper and iron

sulphides. The shales contain large quantities of iron oxides and perhaps small quantities of calcium carbonate, although not in the form of limestone.

CHEMICAL REACTIONS

We can write out chemical equations showing how metallic copper might have been formed from such associations, thus:

$$\text{I. } 3CuSO + Fe_2O_3 = 3CuO + Fe_2(SO_4)_3.$$
$$\text{II. } 3Cu_2SO + Fe_2O_3 = 3Cu_2O + Fe_2(SO_4)_3.$$
$$\text{III. } CuSO_4 + CaCo_3 = CuO + CaSO_4 + CO_2.$$

The copper oxides produced by one or more of the above equations could readily be reduced to metallic copper by the action of ferrous sulphate in the presence of traces of free sulphuric acid, thus:

$$\text{IV. } CuO + 2FeSO_4 + H_2SO_4 = Cu + Fe_2(SO_4)_3 + H_2O.$$
$$\text{V. } Cu_2O + 2FeSO + H_2SO_4 = 2Cu + Fe_2(SO_4)_3 + H_2O$$

ORIGINAL SOURCE OF THE COPPER

The original source of the copper is difficult to determine. The nearest known copper beds are to the south more than a hundred miles. If the source were the Red beds themselves, then the copper must have been gathered from the immediate surface, or possibly from material already removed by erosion, for it could not have been leached from the surrounding shales without the leaching process having made a greater change than has occurred. At present the surface waters, of course, are charged with organic matter, the same as other surface waters where vegetation is abundant, but the iron oxide of the shales oxidize such matter while yet near the surface, as is shown by the red color for 20 feet above the copper bed.

Remarks upon the subject of the paper were made by W. H. Hobbs, J. F. Kemp, and the President.

The third paper was read by title:

ANDESITIC ROCKS NEAR SILVERTON, COLORADO

BY FRANK R. VAN HORN

Contents

Introduction

In the summer of 1898, while spending a few weeks at Silverton, San Juan county, Colorado, in the study of the mines and economic geology of the region, the rocks which are the subject of this paper were collected. The fundamental rocks of the neighborhood seem to be granites and granito-diorites associated with gneisses and schists. Over these follow several lava flows, probably of Tertiary age, in succession, accompanied in some localities by considerable tuff, which has

become consolidated into breccia-like masses. No attempt was made to trace the different flows from one place to another, and the specimens were simply taken at random in the different localities. However, in view of the fact that most of them were collected at altitudes of from 12,000 to 14,000 feet, it seems very probable that the younger flows were gathered. Most specimens were collected on King Solomon, Galena, and Boulder mountains, which lie in a northerly direction from Silverton, covering a triangular area. However, while there I had neither map nor instrument with me and my points of the compass may not be very accurate.

The rocks of this locality, although apparently all of the same kind, differ considerably in appearance and texture. The specimen which was least altered, and therefore most typical, was found at the summit of the southeast spur of Galena mountain, above the Big Ten claim, which at that time was being exploited by Mr A. M. Campbell and associates. It is this rock which will serve as the basis of the description for all the rocks of the region. Nevertheless, various characteristics not found in this specimen but observed on others will be incorporated into the description of this rock, in order that a general account may be given without taking too much time and space.

Megascopic Description of the Rock

Megascopically the rock in question is of gray color, with numerous phenocrysts of plagioclase feldspar, hornblende, and magnetite in an aphanitic groundmass. The phenocrysts are arranged in some instances in roughly parallel directions as a result of flowing. This rock effervesces but slightly with acids, while others do so very strongly. The prevailing color of the rocks is grayish green, but at times a brownish to reddish gray was noted. Sometimes the phenocrysts are very numerous and give the rock almost a plutonic appearance, while again they are nearly absent, and the mass has an aphanitic character. Often the plagioclase crystals are from 3 to 5 millimeters long and 2 to 5 millimeters across. However, in the rock from Dives tunnel, given in the analyses, the feldspars are at times 19 millimeters long and from 6 to 13 millimeters wide. When unaltered the cleavage faces have pearly luster, but they are quite commonly dull. The hornblende is black, with smooth glistening cleavage planes, and is not found in very large amounts. Magnetite is plentiful and is generally titaniferous, as is shown by microscopic examination.

Microscopic Observations

Microscopically, the rocks are found to be distinctly holocrystalline porphyritic, although at times the groundmass is so intensely fine as to be almost cryptocrystalline.

Plagioclase phenocrysts occur in various forms, but are probably generally tabular parallel to the brachypinacoid (010), being bounded by the prisms (110) $(1\bar{1}0)$, brachypinacoid (010), base (001), and a macrodome. The crystals are generally twinned after the Albite law, and very frequently compound twins after Albite and Karlsbad laws are found. Pericline twins occur more rarely. Zonal structure is frequently observed, and at times is very common. When such structure is noticed, the extinction angles of the center are always found to be considerably greater than those of the periphery, which indicates isomorphous growths of the

various plagioclase. Cleavage is good after both (001) and (010). The rock given under analysis I was pulverized by stamping and the minerals isolated by means of the Klein solution. A small portion of feldspar had the specific gravity 2.69–2.684 at 22 degrees centigrade. Extinction angles on P (001) were found to range about 8–10 degrees, while on untwinned pieces, evidently after M (010), values of 20–23 degrees were found. Most of the feldspar has a specific gravity of 2.684–2.64 at 22 degrees centigrade, in which angles on P (001) were found from 0–7 degrees, while a few angles of 12–17 degrees were observed on particles evidently cleaved after M (010). The latter gave in convergent light an axial figure intermediate between that of oligoclase and labradorite. Another considerable portion ranges from 2.64–2.604 at 22 degrees centigrade, but it was found to consist mainly of groundmass; in fact, the portion from 2.684–2.64 had considerable groundmass mixed with it.

The foregoing observations, together with the maximum symmetrical extinction angles given in sections normal to M (010), indicate that the phenocrysts are members of the andesine and acid labradorite series. The successive occurrence of these, with even other plagioclase not mentioned, is not to be wondered at in view of the frequent zonal structure; since particles belonging to the same crystal may give extinction angles ranging from those of labradorite to oligoclase, as was observed in a few cases. It is extremely probable that the plagioclase phenocrysts of the majority of the rocks are more basic than in the present instance, which is the most acid rock of the series. Symmetrical extinction angles of 25–27 degrees in the zone normal to (010) with Albite twins and Karlsbad twins with differences in the two sides of 12–15 degrees would seem to point out that the more basic labradorites play an important part in many of the rocks under investigation. The plagioclase decompose first along cleavage and twinning directions, except perhaps when zonal structure is present, in which case the alteration begins at the center of the crystal. The secondary minerals resulting from the feldspars were found to be calcite, mica, kaolin, epidote, and possibly chlorite, as the result of mutual reaction of solutions originating from plagioclase and the dark minerals. Quartz was at times present in small amounts, but whether it resulted from the feldspars or other minerals could not be stated. Of these alteration products calcite was probably most common, then come mica, either paragonite or muscovite, and, finally, epidote, the remainder of the decomposition products being rarer.

Hornblende is the next most important constituent after the plagioclase. It is pleochroic with $\mathfrak{c}$ and $\mathfrak{b}$ = brown, $\mathfrak{a}$ = yellow with a tinge of brown. The crystals are generally idiomorphic, being bounded by the prism (110), clinopinacoid (010), and terminated evidently by pyramid and dome faces. At times, however, the mineral occurs in bizarre forms, which are due to resorption. Twins were observed after the orthopinacoid (100). Cleavage is good after the prism (110) and cleavage fragments gave an extinction of 11–13 degrees, which would probably yield values of 14–16 degrees on (010). Indications of zonal structure were also observed. All of these facts indicate a typical basaltic hornblende. Through decomposition the mineral loses its color and the pleochroism becomes weaker, but the double refraction does not change. Along the outer parts of the mineral a mass of fine dark grains of iron oxide, which at times is hematite, accumulates, giving the hornblende at first glance an appearance of zonar structure, or perhaps of resorption rims. This could not be the fact, however, as the rims increase in width with growing decomposition. In some cases the alteration does not pro-

ceed farther than this stage, but at other times complete alteration to chlorite and calcite is found. Hematite is also seen deposited on the cleavage cracks, and epidote occasionally is a secondary product.

Augite in small colorless or pale green crystals occurs at times. The amount, however, never seems to be great. The mineral is bounded by (110), (010), and (100) in the prismatic zone, as usual. Cleavage after (110) is present, but not well developed. Twins after (100), sometimes polysynthetic, are found. Extinction in sections near (010) is 42 degrees. The augite seems to alter more readily than hornblende to chlorite, calcite, and epidote, so that the maximum amount of augite can never be ascertained. It seems certain, however, that this mineral plays a less important part in these rocks than the hornblende.

Magnetite is always present in considerable quantity in both phenocrysts and groundmass. It occurs in well defined octahedrons, sometimes twinned after the Spinel law. The mineral decomposes to hematite and limonite. In advanced stages of alteration the presence of leucoxene rims around the surfaces, as well as along the parting planes, proves that the mineral is titaniferous. Occasionally the shape of the crystals and amount of leucoxene is such as to indicate ilmenite, but the fact that the substance is so strongly magnetic bespeaks magnetite.

Apatite in short hexagonal prisms, terminated evidently by base and pyramid, is generally present in and near the magnetite.

A mineral having the properties of zircon is found very sparingly.

The groundmass, which megascopically is always aphanitic, is, so far as could be observed, holocrystalline. It consists mainly of plagioclase microlites, both twinned and untwinned, often woven into a felt-like or pilotaxitish structure, but sometimes possessing a parallel arrangement due to flowing. In rock number I, which was separated by means of the Klein solution, a quantity of the groundmass was found in the portion having the specific gravity 2.684–2.64 at 22 degrees centigrade. However, most of the groundmass seems to be included in the quantity having the specific gravity 2.64–2.604 at 22 degrees, while a very small portion ranges from 2.604–2.578 at 22 degrees, which was the lightest portion found in the rock. Although these masses were not pure, still a good idea is given of the limits within which the groundmass is confined. Extinction angles in sections normal to (010) and angles measured with reference to the long directions of the microlites gave values from 0 degrees up to 7–9 degrees. It seems safe, even from the specific gravities, to conclude that the groundmass consists of oligoclase-andesine, perhaps with some albite, in contradistinction to the andesine-labradorite of the phenocrysts. The specific gravity 2.578, at which all particles of the rock had slowly fallen, shows that there could be no glass present in the groundmass. Besides plagioclase, the groundmass contains innumerable specks of what seem to be magnetite, together with a few other minerals in small amounts, which are largely secondary products, like calcite, epidote, and chlorite.

Chemical Composition *

The analyses were made in the chemical laboratory of Case School of Applied Science, under the direction of Doctor A. W. Smith, by the students of the college.

* Messrs E. W. Gebhardt and W. G. Haldane, who made analyses II, III, IV, V, VI, VIII, and IX, chose the chemical study of these rocks as a subject for the degree of bachelor of science. Analysis I was executed by Mr E. O. Cross, while VII was analyzed by Mr E. B. Willard. To all of these gentlemen my thanks are due for their work.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	61.36	58.36	57.38	57.29	56.93	56.36	55.77	55.68	54.22
TiO_2	Undet.	1.49	2.22	1.42	.96	.83	.34	1.45	1.65
Al_2O_3	16.56	16.13	16.30	19.93	17.61	15.46	16.38	17.09	16.69
Fe_2O_3	3.44	3.85	3.70	2.95	3.04	5.00	4.27	5.26	3.63
FeO	2.93	3.25	2.66	3.39	3.24	1.85	4.17	1.98	3.39
MnO	Undet.	.66	1.70	.75	2.23	1.49	Undet.	1.56	1.43
MgO	.85	2.91	1.61	1.55	1.77	2.00	3.10	2.23	2.72
CaO	4.56	3.57	5.12	5.67	5.03	5.28	6.66	5.05	5.86
Na_2O	6.86	4.51	3.58	3.34	3.97	4.91	3.65	2.83	4.82
K_2O	1 30	2.41	2.29	1.92	2.93	2.73	2.37	1.95	2.20
H_2O	1.55	1.61	1.08	1.53	.74	1.34	2.36	1.50	1.55
CO_2	traces.	1.54	2.66	none.	1.45	1.92	1.58	2.97	2.53
	99.41	100.29	100.30	99.94	99.72	99.17	100.65	99.55	100.69
Specific gravity	2.63	2.655	2.745	2.66	2.70	2.735	2.745	2.725	2.695

I. Hornblende-andesite, summit of southeast spur of Galena mountain, above Big 10 claim, near Silverton, Colorado.

II. Hornblende-andesite, tunnel of Dives claim, upper level, King Solomon mountain, near Silverton, Colorado.

III. Hornblende-andesite, west slope of Boulder mountain, 1½ miles north of Silverton.

IV. Hornblende-andesite, from Middleton, 6 miles northeast of Silverton, on east side of road.

V. Hornblende-andesite, 30 feet from hanging wall of Big 10 vein, Galena mountain.

VI. Hornblende-andesite, country rocks of Dives claim, upper level of King Solomon mountain.

VII. Hornblende-andesite, Little Giant peak of King Solomon, slightly below summit toward Cuningham gulch.

VIII. Hornblende-andesite, summit of Little Giant peak of King Solomon mountain, about 14,000 feet above sealevel.

IX. Hornblende-andesite, hanging wall of Big 10 vein (east side), Galena mountain, near Silverton, Colorado.

The analyses show at first glance that the rocks are of andesitic character, and also that they are badly decomposed. All the rocks have a similar character, with a tendency to form a series, ranging from acid to basic members. However, if the CO_2 were calculated to the remaining constituents, the basic end of the series would not be so low. Nevertheless these rocks belong to the basic rather than to the acid andesites. In the analyses the constant presence of considerable TiO_2 and MnO is to be noted. The TiO_2, as before mentioned, is probably to be found in the magnetite. The fact that the microscope shows the presence of apatite in small quantities will partially explain the fact that some of the analyses are too low, as P_2O_5 was not determined. The advanced stage of alteration of these rocks will also explain other seeming irregularities in the analyses. In many cases the rocks have undoubtedly been altered by the ore-bearing solutions which have deposited most of their material in the veins of the district.

Conclusion

The rocks in the neighborhood of Silverton, Colorado, comprised in the triangular area bounded by Galena, King Solomon, and Boulder mountains are horn-

blende-andesites of rather basic character, having a holocrystalline porphyritic texture with phenocrysts of andesine-labradorite, basaltic hornblende, augite, magnetite, and apatite in a pilotaxitish groundmass of oligoclase-andesine and magnetite. These rocks are rarely fresh, but generally very much altered—a fact which renders them difficult as well as unsatisfactory material for investigation. In many cases the decomposition has been caused largely by the action of ore-bearing solutions, an example of which is especially noticeable in analyses V and IX.

The fourth paper presented was

EVIDENCES OF INTERGLACIAL DEPOSITS IN THE CONNECTICUT VALLEY

BY CHARLES H. HITCHCOCK

[*Abstract*]

The evidences of interglacial deposits in the Connecticut valley are derived from the study of the eskers, notably the one passing through Hanover, New Hampshire, which has been followed for thirty miles between Thetford and Windsor, Vermont. The esker was formed in caves or open gorges while the ice was still moving down the valleys, and it represents glacial action. Hence the underlying deposits represent what was earlier or interglacial. In searching for the base of this esker I found it to be modified drift. It is mainly a compact clay containing the curious massive concretions described in the "Geology of Vermont" as coming from Sharon. This I find at several localities in the village of Hanover, revealed by recent excavations. There is a later widely disseminated clay not indurated and passing into silt, besides containing tubular ferruginous concretions, which belongs to a later period. Besides the clay I discover a thick sand higher up, and hence intermediate between the lateral terraces and the till, which seems to represent an older deposit. Dunes blown from this were described by Upham* in Lebanon, Plainfield, Cornish, Charlestown, etcetera, always on the east side of the valley. The dunes are absent from the west side of the valley, but the deposit is present, sometimes associated with a tough clay.

This lower clay has been tilted and contorted, as in the vale of Tempe, where the wrinkling is comparable with the minute corrugation of crystalline schists. The combined induration and folding are regarded as effects of pressure induced by the overlying glacier.

For two miles along the east bank of the Connecticut this esker is continuous at a uniform height, cut across by Mink brook, Tempe brook, and at length by the main river. I find valleys of drainage pointing across this ridge at two points where artificial excavations have been made—one for a road to cross the Ledyard bridge and the other for a sewer a mile north. The drainage must have taken this direction before the formation of the esker and through modified drift.

These facts confirm the correctness of my contention of the existence of a local Connecticut glacier subsequent to the general southeasterly movement of the ice. The presence of what appears to me to be this same glacial lobe is predicated by the observations of Professor B. K. Emerson in Monograph XXIX of the United

* Geology of New Hampshire, part iii, page 41 et passim.

States Geological Survey, 1899. Upon the four sheets, plate xxxv, A, B, C, D, thirteen ice barriers obstructing tributary valleys and thereby producing high level sands are represented upon the east side and fifteen upon the west side. Most of them extend northerly and southerly, because the obstructing ice occupied the main valley. Other ice-tongues seem to have similarly occupied the Deerfield and Millers river valleys.

It has been objected to the existence of local glaciers that the flow of the lower ice was influenced locally by the topography. This fact is conceded for the time of excessive ice accumulation, and then it will be the valley rocks which will be transported downward; but the esker is characterized by the presence of the valley rocks, and they must have been transported even after the accumulation of some modified drift. I refer to the fragments of white mountain porphyries which are common in the esker, but have not yet been discovered in the neighboring till. These fragments increase in number and rise as one ascends the valley of the Ammonoosuc, and constitute there an upper till overlying the ground moraine.

The presence of this lobe of ice may confirm the contention of Mr Upham, that certain tributary deltas are higher than the normal principal terrace of the Connecticut. The side stream may occasionally discharge an abnormal amount of water which would pile up an unusual amount of sediment.

Following the reading of Professor Hitchcock's paper the Society adjourned, at 12.40 o'clock, for the noon recess. At 2.10 o'clock the Society reconvened and listened to a second paper by the same author.

VOLCANIC PHENOMENA ON HAWAII

BY CHARLES H. HITCHCOCK

Remarks were made by W. H. Hobbs and by visitors. The paper is printed in full in this volume.

The next paper was

A THEORY OF ORIGIN OF SYSTEMS OF NEARLY VERTICAL FAULTS

BY WILLIAM H. HOBBS

[*Abstract*]

The point is first emphasized that joints and faults probably differ in degree of displacement chiefly, and that prismatic fault systems formed of two parallel and intersecting series may be explained by simple compression of a section of crust in the same way that prismatic systems of joints have been accounted for by Becker and others. The conditions of rupture under compression are discussed (*a*) for a homogeneous crustal block without preexisting structure planes, and (*b*) for a crustal block possessed of a network of vertical fault planes. Stress is laid upon the fact, too often overlooked, that an isotropic block during compression is in the anisotropic condition of a non-isometric crystal.

The relative depression of a crustal block along vertical rupture planes due to inadequate support of its load receives an independent discussion. In every area where relative depression occurs there is a closed line, which may be termed the

margin of the area of no vertical stress, or for brevity the line of no vertical stress, along which and without which there is no vertical component of the stress due to load, but about which act the moments of the load within the overloaded area. The convergence of vertical planes downward imposes a restraint upon the depression of a crustal block within vertical walls, and tends to form new rupture planes if the thickness of the crustal block be small in comparison with its area.

The principles discussed are applied to explain the observed faults within the valley of the Pomperang river, Connecticut.

The following paper was read by the author, who was introduced by J. M. Clarke:

HUDSON RIVER BEDS NEAR ALBANY AND THEIR TAXONOMIC EQUIVALENTS

BY RUDOLF RUEDEMANN

[*Abstract*]

This paper is the first installment of an investigation of the belt of so-called Hudson River beds, extending on both sides of the Hudson river in eastern New York. It gives the results obtained between the mouths of the Mohawk river and Coeymans Kill.

The uniform mass of shales and sandstones with conformable easterly dip, which hitherto, as "Hudson River beds," has been considered as representing the time interval between the Utica and Oneida ages, can, by means of the entombed faunas, be separated into Lower, Middle, and probably Upper Trenton beds, Utica shale, and Lorraine beds. All of these stages are represented by belts of similar rocks, extending from west-northeast to south-southeast with the general strike of the rocks. The whole series is overturned, being the underturned wing of an overturned fold of Appalachian type.

Remarks were made by J. M. Clarke.

The three following papers were read by title:

FAUNA OF THE ARENACEOUS LOWER DEVONIC OF AROOSTOOK COUNTY, MAINE

BY JOHN M. CLARKE

GIANTS' KETTLES ERODED BY MOULIN TORRENTS

BY WARREN UPHAM

This paper is printed in full in this volume.

PLEISTOCENE ICE AND RIVER EROSION IN THE SAINT CROIX VALLEY OF MINNESOTA AND WISCONSIN

BY WARREN UPHAM

This paper is printed in full in this volume.

After announcement of excursions under the guidance of Professor J. F. Kemp, the Society adjourned.

Register of the New York Meeting, 1900

The following Fellows were in attendance upon the session of the Society:

J. M. Clarke.
G. M. Dawson.
H. L. Fairchild.
G. K. Gilbert.
Erasmus Haworth.
R. T. Hill.
C. H. Hitchcock.
W. H. Hobbs.
Arthur Hollick.
J. A. Holmes.
E. O. Hovey.
A. A. Julien.
J. F. Kemp.
W J McGee.
E. B. Mathews.
F. H. Newell.
R. D. Salisbury.
H. W. Turner.
T. G. White.
S. W. Williston.

Present at the meeting of the Society, 20.

The following Fellows were in attendance upon the meeting of Section E, American Association for the Advancement of Science:

W. B. Clark.
J. E. Todd.

Fellows-elect

L. C. Glenn.
Stuart Weller.

Total attendance, 24.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 13-24 NOVEMBER 30, 1900

PLEISTOCENE ICE AND RIVER EROSION IN THE SAINT CROIX VALLEY OF MINNESOTA AND WISCONSIN

BY WARREN UPHAM

(Read before the Society June 26, 1900)

CONTENTS

INTRODUCTION

The theme of this paper was first considered somewhat fully by the present writer in a lecture, March 18, 1896, entitled "The Saint Croix river before, during, and after the Ice age." This lecture was given at Taylors Falls, Minnesota, as one in a series designed to direct public attention to the Interstate park, recently set apart by legislative enactments of Minnesota and Wisconsin, on each side of the Saint Croix river at its Upper Dalles, closely adjoining the towns of Taylors Falls, Minnesota, and Saint Croix Falls, Wisconsin. The series of lectures was published in 1896 by Honorable George H. Hazzard, the Interstate Park Commissioner of Minnesota; but my lecture was withheld from publication in geologic literature, excepting very brief notes,* on account of my hope for further opportunities of field observation and study of this subject.

My chief conclusion, that in the Glacial period the Saint Croix river first began to occupy the part of its valley including the rock gorges of the Upper and Lower Dalles, was soon accepted by Doctor Charles P.

*Am. Geologist, vol. 17, p. 260, April, 1896, and vol. 18, p. 223, Oct., 1896.

Berkey* and Mr A. H. Elftman,† who each made extensive field studies of this district. They differ from me, however, in referring the erosion of the new part of the valley to late Glacial and postglacial time, instead of which it seems to me to belong to an interglacial stage or epoch. Probably its date was the same as that of the erosion of large watercourses in the drift-sheet of Martin county, on the southern border of Minnesota, which, having become in part and irregularly filled by later drift, are marked by three very remarkable chains of lakes.‡

Subsequently I have again several times examined the portions of this valley next below and above the Dalles, confirming the view that the new course of the river and much of its gorge erosion are referable to a long interglacial stage which in the Mississippi basin followed the Kansan stage of maximum glaciation.

During that time of extensive recession of the border of the ice-sheet, the Saint Croix river appears to have channeled this part of its valley and its gorges in the Dalles, thereby uniting two hydrographic basins, which previous to the Ice age had been each separately tributary to the Mississippi. After the readvancing ice-sheet had again reached southward nearly to its previous limit west of the Mississippi, and even beyond it in Illinois and eastward, this river during the final departure of the ice, in the closing Wisconsin stage of the Glacial period, carried for some time a much greater volume of water than now, being temporarily the outlet of a great lake dammed by the barrier of the northeastwardly receding ice border in the western part of the Lake Superior basin. The beds of the Saint Croix and Mississippi, southward from the Dalles, were then channeled considerably below their present depths, and by later partial refilling with sand and gravel they have come to be occupied in the unfilled portions by lake Saint Croix and lake Pepin.

The Saint Croix River and Basin

Measured along the general course of the valley, and without including the minor bends and meandering of the river, its length from source to mouth is about 150 miles. At first it runs southwestward about 75 miles; then east and southeast about 25 miles, to Taylors Falls, and, lastly, south about 50 miles. In the southern half of the distance last noted it is expanded to the width of a half mile to one mile, forming

* "Geology of the Saint Croix Dalles," part I, Am. Geologist, vol. 20, pp. 345–383, with maps and sections, Dec., 1897. This paper is continued by parts II and III, on the mineralogy and paleontology of the rock formations, in vol. 21, pp. 139–155 and 270–294, with maps and plates, March and May, 1898.

† "The Saint Croix River valley," Am. Geologist, vol. 22, pp. 58–61, July, 1898.

‡ Geology of Minnesota, vol. 1, 1884, pp. 479–485, with map at page 472.

the lake Saint Croix. Several large tributaries flow to the Saint Croix river from each side, and the maximum width of the drainage basin is about 80 miles, from the beginnings of the Kettle river in Minnesota southeast to the farthest springs of the Yellow river in Wisconsin.

According to Mr James L. Greenleaf, in his "Report on the water power of the Mississippi river and some of its tributaries," contained in volume 17 of the quarto final reports of the tenth United States census, for 1880, published in 1887, the drainage area of the Saint Croix comprises 7,576 square miles, of which slightly more than half lies in Wisconsin. The volume of the river at its mouth in the stage of low water is stated to be 2,800 cubic feet per second, and the average flow about 6,200 cubic feet per second for the whole year.

The chief tributaries from Wisconsin are the Namekagon river, stated by Greenleaf to be 85 miles long, draining an area of 1,025 square miles; the Yellow river, 50 miles long, draining 310 square miles; the Clam river, also 50 miles long, draining 416 square miles; Wood river, 30 miles long, draining 168 square miles; Apple river, 55 miles long, draining 427 square miles; and Willow river, 35 miles long, draining 246 square miles.

From Minnesota the Saint Croix receives the Kettle river, noted as 70 miles long, with the largest tributary drainage area, 1,093 square miles; the Snake river, 78 miles long, draining 937 square miles; and the Sunrise river, 30 miles long, draining 292 square miles.

TABLE OF ALTITUDES

The following altitudes along the Saint Croix river, given in feet above the sea, from leveling by United States engineers in surveys for converting some of the abundant lakes of its head streams into a reservoir system, and from railroad surveys, show that the main stream has a descent of about 400 feet:

	Feet
Springs at head of the South branch of the Bois Brulé river	1,068
Springs at head of the Saint Croix river	1,070
(These springs rise in the same marsh, 600 feet apart, the Bois Brulé river running north, the Saint Croix south. An ancient watercourse exists here, mainly about a mile wide, bordered by drift bluffs 75 feet high, with their crests 1,140 to 1,150 feet above the sea. It was the outlet of lake Superior when the receding ice-sheet on the northeast, acting as a barrier to the present course of outflow, held this lake about 500 feet higher than now.)	
Upper Saint Croix lake	1,011
Saint Croix river at Gordon, Wisconsin	1,006
Same, low water, above and below the "Big dam"	1,005 and 1,001

	Feet
Same at Moose River rapids	987
Mouth of Namekagon river	912
Mouth of Yellow river	892
Mouth of Clam river	870
Head of Kettle River rapids (4 miles long, falling 49 feet)	858
Mouth of Kettle river, west of the "Big island"	824
Foot of Kettle River rapids	809
Mouth of Snake river	798
At bridge of the Grantsburg branch, Saint Paul and Duluth railroad	775
At Rush City ferry	770
Mouth of Sunrise river	758
Mouth of Trade river	753
Head of Saint Croix rapids (6 miles long, falling 53 feet)	742
Mouth of Big Rock creek	726
Foot of Saint Croix rapids, at the town of Saint Croix Falls	689
At Taylors Falls, the head of steamboat navigation, three-fourths of a mile below the last	687
At head of Rock island	685
At Osceola	683
At bridge of the Minneapolis, Sault Ste. Marie and Atlantic railway, bed, 670; low and high water	680–697
Mouth of Apple river	672
At bridge of the Wisconsin Central railroad, bed, 666; ordinary low stage of water, 676; extreme low and high water	670–689
Lake Saint Croix (maximum depth, 25 feet), extreme low and high water, 667–687; ordinary stage	672
Junction with the Mississippi river at Prescott	667

Preglacial Rivers in the Saint Croix Valley

The very long Tertiary era, preceding the Ice age, had permitted the larger streams of Minnesota and Wisconsin to erode deep and wide, well matured valleys, free from waterfalls or strong rapids, and having no narrow, rock-walled gorges, like the Dalles of the Saint Croix. But in the northern, drift covered part of the United States, and throughout Canada, the rivers, on their again coming into existence when the ice of the Glacial period melted away, found themselves in many places turned aside from their preglacial courses by the drift deposits and by the movements of continental uplift and subsidence that were associated with the Ice age. In some cases formerly independent streams were thus united to make a single larger river system; and often a river was turned out of its old drift-filled valley for a comparatively short distance, as a few miles, being there compelled to cut a new gorge in the bed-rocks.

One or the other of these results of the Glacial period has been well ascertained as the fortune of so many rivers in the great drift-covered

region that the occurrence of the two short, grandly picturesque rock gorges, or canyons, known as the Upper and Lower Dalles of the Saint Croix, so named by the French voyageurs in allusion to their inclosing walls of rock, strongly suggests that there the stream is now flowing in a course which it has cut during and since the Ice age. No closely adjacent belt, however, seems to be probably identifiable as a drift-filled preglacial valley. Therefore, from my studies, for the Minnesota Geological Survey, of the country extending many miles westward from the Saint Croix, I conclude that in preglacial times this river was represented by two quite independent rivers, each flowing into the Mississippi.

The greater part of the Saint Croix drainage basin, including all above the rapids, six miles long, which end at Saint Croix Falls and Taylors Falls, I think to have belonged before the Ice age to a river flowing south and southwest from the principal elbow of the present Saint Croix, taking approximately the course of the Sunrise river, which, however, now runs northward, and traversing Anoka county to a junction with the Mississippi somewhere between Anoka and Minneapolis. Thence, as Professor N. H. Winchell has shown, the preglacial course of the Mississippi probably passed southeastward.* It may have coincided nearly with the site of lake Phalen, close northeast of Saint Paul, running thence south two miles to join the present valley near the State Fish Hatchery, where the northeastern bluff of the Mississippi for a distance of about a mile consists of morainic glacial drift without rock outcrops. Between lake Phalen and this place, a well at the Saint Paul Harvester works, about 863 feet above the sea, penetrated 235 feet of drift deposits before reaching the bed-rock, thus revealing the existence of a preglacial channel eroded there by a river that flowed at a level 55 feet below the present Mississippi.†

A broad, low belt of sand and gravel plains stretches across the distance of nearly 40 miles from the Saint Croix to the Mississippi at Anoka, nowhere having a greater height than 150 feet above the elbow of the Saint Croix and the mouth of the Sunrise river. On the east, between that low tract and the Saint Croix valley, a belt of rolling and hilly glacial drift or till underlain in part by the bed-rocks at a greater altitude than the sand and gravel area westward divides it from this valley. It seem to me more likely therefore that the old river passed far west and south, to Anoka and Saint Paul, than that it took the course sug-

*"An approximate interglacial chronometer," Am. Geologist, vol. 10, pp. 69-80, with sections and a map, August, 1892. On this map the probable preglacial and interglacial channels of the Mississippi in the vicinity of Minneapolis and Saint Paul are delineated, differing much from its present course.

†Geology of Minnesota, Final Report, vol. 2, 1888, pp. 361-363.

gested by Mr Elftman, from the Sunrise river by Chisago lake to rejoin the present Saint Croix valley.

About a sixth part of the Saint Croix basin, lying east and south of Taylors Falls, appears to have been drained during the Tertiary era by a stream coinciding nearly with the Apple river and the lower 30 miles of the Saint Croix river. The large basin and river first described may be called the preglacial Saint Croix, and the lower small stream may be distinguished as the enlarged preglacial Apple river.

These Tertiary drainage areas, which by the vicissitudes of the Ice age became united into one stream, the present Saint Croix, I think to have been divided, up to the time of the ice accumulation in the Glacial period, by a watershed of the very old trappean and Cambrian rocks, extending from northeast to southwest across the sites of the towns of Saint Croix Falls and Taylors Falls.

Pleistocene Erosion of the Dalles

In the twenty-third annual report of the Minnesota Geological Survey for the year 1894 I have stated (on pages 188–190) the evidence that the recession of the ice-sheet during the Buchanan interglacial stage, which succeeded its Kansan stage of maximum area west of the Mississippi, extended northward beyond the site of Barnesville, Minnesota, on the southern part of the great valley plain of the Red river of the North. Probably at that time the ice had been melted away from nearly or quite all of the southern half of Minnesota. That the retreat of the ice-sheet had uncovered the southern third of the Saint Croix basin is shown, in Nessel township, Chisago county, Minnesota, near Rush City, by an interglacial Buchanan land surface, with wood and peaty matter, upon a deposit of modified drift that was laid down during the previous retreat of the ice.* Above the wood and peat of this place, and above an extensive plain of the Buchanan modified drift reaching thence several miles eastward, a somewhat uniform mantle of till, 10 to 20 feet deep, was spread during the ensuing Illinoian and Iowan glacial readvance.

We thus know that the district including the Dalles and extending northward at least to Rush City was uncovered from the ice-sheet during the Buchanan stage of the Glacial period. Later the increasing snowfall again permitted nearly all this basin to be enveloped by the ice of the Illinoian and Iowan stages, reaching on the Saint Croix river southeasterly to the conspicuous moraine belts which pass from Saint Paul and Minneapolis northeastward to the northern half of lake Saint Croix

* Geology of Minnesota, vol. 2, 1888, pp. 414, 418.

and through the southeastern part of Chisago county, continuing thence onward in Wisconsin.

Terraces of sand and gravel, which are found in the Saint Croix valley 4 to 10 miles north of Taylors Falls, mostly having a height of about 90 feet above the river, are remnants of valley drift deposited during the Wisconsin stage of the final departure of the ice-sheet. These gravel deposits, continuous as one expanse of modified drift from the "jack pine barrens" of northwestern Wisconsin, bear testimony that a part of the floods from the dissolving ice then passed southward along the present Saint Croix, and that the erosion of the valley in the vicinity of the Dalles had been mainly accomplished previous to the Wisconsin stage. We are led, therefore, to the conclusion that much channeling of the valley here, enlarging it along all its course from the Dalles southward to the Apple river, and eroding the drift bluff, an escarpment of till, which rises steeply on the west side of the valley at Taylors Falls and northward to the height of 200 to 220 feet above the river, took place mostly during the prolonged Buchanan interglacial stage. It was a nearly similar history with that of the Minnesota river during the same Buchanan time in the reexcavation of its valley, which had doubtless become chiefly filled with drift during the principal Kansan stage of glaciation.

When I wrote the chapter on this district for the final report of the Minnesota Geological Survey (volume 2, 1888, pages 399–425, with map of Chisago, Isanti, and Anoka counties), I believed that the preglacial and postglacial courses of the Saint Croix were alike; but I now attribute the establishment of this great river course and valley at the Dalles, and for many miles above and below, to the capricious outlines of the retreating ice-front in Buchanan time, probably sending a considerable stream across the preglacial watershed and along this course at first because the ice itself was still a barrier on the lower country westward. The erosion by this stream had cut down this section of the valley and the two gorges of the Upper and Lower Dalles so far before that lower land was uncovered from the ice that the channel so begun still continued as the lowest then available for the river, and the erosion apparently extended as deep as to the present river level before the renewal of ice accumulation.

The duration of the interglacial stage attended by great decrease of this part of the continental ice-sheet has been estimated by Winchell, from his investigation of the drift-filled gorge of the Mississippi west of Minneapolis, to have measured about 15,000 years.* Within that time,

* Paper before cited in the American Geologist (vol. 10), estimating the interglacial stage as 9,750 years; which is corrected to about 15,000 years in the same volume, p. 302, Nov., 1892.

preceded and followed by long stages of glaciation of this distr drainage from an embayment of the ice boundary. at the jun glacial currents flowing in Minnesota from the northwest and consin from the northeast, passed in a large river, the interglaci Croix, across the former watershed where we now have the gorge Dalles.

Separate preglacial streams flowing from this locality southwa northwestward during many thousand years of the Tertiary era now continuous river course, had doubtless performed the great of the valley erosion on each side of the old watershed, which it may also believe, was deeply indented here by a col of the tr rocks in which the Dalles are channeled. The separate valleys each way from the col, as eroded during the very long Terti may have attained nearly the same size which they now have of the present continuous valley, varying mainly from about a h to one mile in width and from 75 feet to about 150 feet in depth the adjoining rock cliffs.

In the Upper Dalles, at and just south of Taylors Falls, extendin two-thirds of a mile, and again in the Lower Dalles, situated tw farther down the river and reaching one-third of a mile, imme above the village of Franconia, Minnesota, the rock cliffs of tr weenawan diabase, rise almost or quite perpendicularly on each the river, inclosing it at each place by a very picturesque gorg vertically jointed and castellated walls of the Upper Dalles form from 200 feet to about 500 feet wide, which turns at a sharp angl central part from a course nearly due south to another bearin southwest. The course of the Lower Dalles, about 500 feet wide, west-southwest, this direction being in each case determined by cipal system of parallel and nearly vertical joint planes.

Between these diabase gorges the valley widens to about a m western rock wall being an escarpment of almost horizontally Cambrian sandstone and shales, easily eroded, while on the ea inclosed by irregular slopes of the igneous Keweenawan rocks. tinuing south from the Lower Dalles, the valley, a half mile to on wide, is inclosed by escarpments of the horizontal Cambrian san capped by dolomitic limestone, with overlying glacial drift. Ret and going up the river from Saint Croix Falls, we find its valle inclosed chiefly by eroded drift bluffs.

Glacial erosion in this part of the Saint Croix valley is suppo Doctor Berkey to have been an important factor in causing the r the end of the Ice age to take its present course. It seems to m ever, as before shown, that we may better regard the oppositely f

preglacial streams and the interglacial Saint Croix as the chief agents of the valley sculpture. During the maximum Kansan glaciation the ice-sheet here was doubtless very efficient in planing down the rock surface, and it certainly aided to some degree in shaping the valley. It also acted in the same way during the Illinoian and Iowan stages. But for some time in the closing Wisconsin stage of that later glaciation this district, lying near the glacial boundary and its marginal moraines, was less powerfully pressed and worn beneath the thin ice border, and instead was characterized rather by drift deposition.

Outlet of the Western Superior Glacial Lake

In the western part of the basin of lake Superior the receding ice-sheet held a lake which outflowed southward through northwestern Wisconsin, across the present watershed, between the Bois Brulé and Saint Croix rivers. The highest shoreline of this lake at Duluth is 535 feet above lake Superior (which has a mean level 602 feet above the sea); on mount Josephine, about 130 miles northeast from Duluth, its height, according to leveling by Doctor A. C. Lawson, is 607 feet; and at L'Anse and Marquette, Michigan, 175 and 225 miles east of Duluth, it is found by Mr F. B. Taylor about 590 feet above the lake. The northeastward uplift averages seven inches per mile, and the eastward ascent is approximately three inches per mile.

The latest and lowest of the Western Superior beaches observed at Duluth, occupied by the "boulevard" or pleasure driveway, 475 feet above the lake, on the bluffs back of the city, appears to have an ascent of only about 35 feet in the distance to mount Josephine, showing that the uplift of the land was quite rapidly in progress while the ice-front still maintained the lake at the Saint Croix outlet.

Not long after the glacial retreat passed eastward beyond mount Josephine and Marquette, this lake was lowered and merged with lake Warren across the lowlands of the northern peninsula of Michigan. The vertical interval between the final stage of the Western Superior lake and the level of lake Warren shown by its earliest beach at Duluth was about 60 feet. Thenceforward the outlet of lake Warren past Chicago carried away the drainage from the glacial melting and rainfall of the Superior basin.

The old channel of outflow to the Saint Croix river has a width of about a fifth of a mile in its narrowest place. Its bed is 1,070 feet above the sea, or 468 feet above lake Superior, and it is bordered by bluffs about 75 feet high, showing that when the course of outflow began here the Western Superior glacial lake was about 550 feet above the present

lake level. Probably the highest part of the swamp now forming the watershed in the channel has been filled 20 to 25 feet since the lake forsook this mouth, which was thus lowered by erosion some 100 feet, from 1,150 to 1,050 feet, approximately, above the present sealevel.

Origin of Lake Saint Croix and Lake Pepin

Since the ice barrier which caused the glacial lake Agassiz and the Western Superior lake disappeared, the Minnesota valley and that of the Mississippi below their confluence, and also the Saint Croix valley below Taylors Falls, carrying only a small fraction of their former volume of water, have become considerably filled by the alluvial gravel, sand, clay, and silt, which have been brought in by tributaries, being spread for the most part somewhat evenly along these valleys by their floods. The changes produced by this postglacial sedimentation have been pointed out and ably discussed by General G. K. Warren, who thus added much to our knowledge of the geologic history of these rivers. Lakes Traverse, Big Stone, and Lac Qui Parle occupy hollows in the outlet of lake Agassiz due to inequalities of these recent deposits. At the mouth of the Minnesota river, the Mississippi has brought more sediment than its branch, which is thus dammed for a distance of 30 miles, to Little Rapids, with a depth of 20 to 25 feet at low water. In the same way the Mississippi valley at the mouth of the Saint Croix has become more filled by postglacial deposits than its tributary, which is thus held as back-water 20 miles, to the head of lake Saint Croix, which is 25 feet deep.

Lake Pepin. having a depth of about 60 feet, according to General Warren, lies in the continuation of the valley which was deeply channeled by the outflow from these glacial lakes, because it has become unequally filled below by the deposition of alluvium from the Chippewa river. The depths of lakes Saint Croix and Pepin, however, are only a partial measure of the channeling of the Saint Croix and Mississippi rivers during and shortly after the departure of the ice sheet. The greatest depth of the Saint Croix river, stated by Dr Berkey to be 160 feet near Angle Rock of the Upper Dalles, was worn down probably by the river when it flowed, at the end of the Ice age, along all its lower course, like the lower part of the Minnesota river and the Mississippi thence southward as well, about 100 to 150 feet beneath the present river bed.

Preglacial river erosion in the great valleys had reached far below their present depths, and additional deepening may have occurred during the early and greater part of the Ice age for the Mississippi in the Wisconsin

driftless area and during the long interglacial stage for the more northern valleys. Epeirogenic depression in the Iowan stage, and the consequent melting of the ice-sheet, continuing in the Wisconsin stage and setting free the abundant englacial drift, caused these valleys to be deeply filled by the deposits of the river floods. But soon these deposits were in turn deeply eroded by the rivers, especially where they were outlets of glacial lakes; and during the postglacial period they have been partly refilled, forming the lakes through which the Minnesota, Saint Croix, and Mississippi rivers flow.*

SUMMARY OF THE GEOLOGIC HISTORY OF THE SAINT CROIX DALLES

1. The earliest geologic events directly concerned in making the grand scenery of the Saint Croix Dalles were the eruption of lavas and their subsequent erosion to form steep ridges.

2. Against and on these trap formations, submerged under the Cambrian ocean, were deposited beds of sandstone and shale, which still have nearly their original horizontal position, and which contain shells and impressions of brachiopods and trilobites. The very valuable early geologic explorations and report of David Dale Owen erred in assigning the trap rocks to eruptions bursting through the Cambrian strata. Instead, the more thorough investigations of the Wisconsin and Minnesota geological surveys have ascertained that the trap rocks are the older. Both belong in the far distant geologic past, variously estimated by Dana, Walcott, and others to be some fifty or more million years old.

3. Many geologic periods rolled away, until, after having been long a land area, the western three-fourths or perhaps more nearly all of Minnesota was depressed beneath the sea during the later half of the Cretaceous period.

4. Through the next ensuing Tertiary era, probably comprising some three to five million years, this region was again a land surface, and has continued so onward through the comparatively short Quaternary era, of probably 200,000 years, to the present time, excepting that during the Glacial period it was covered by the ice-sheet. Two entirely distinct Tertiary rivers drained the present Saint Croix basin.

5. The obstructions of the ice-sheet during the Buchanan and Wisconsin stages of the Glacial period caused the Tertiary or preglacial

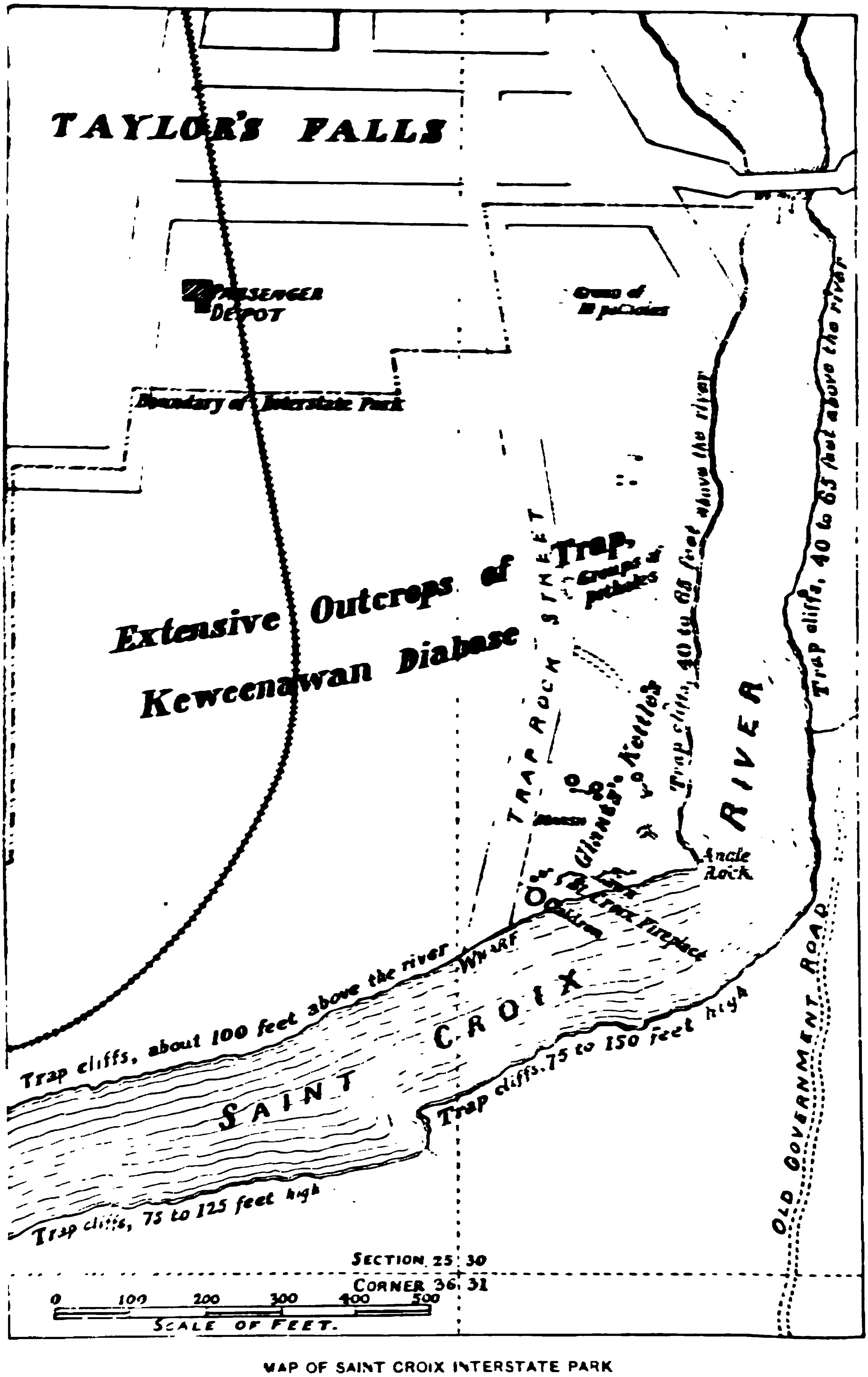
*Compare my paper, "The Minnesota valley in the Ice age," Proc. Am. Assoc. Adv. Sci., vol. 32, for the year 1883, pp. 213-231, noting alluvial deposits in a well at Belle Plaine, 150 feet below the present river, and the record of a well at Lake City, Minn., on lake Pepin, which penetrated beds of stratified clay and of gravel and sand, the modified drift swept into the Mississippi valley during the final recession of the ice-sheet, to the bed-rock about 170 feet below the level of the lake (Minn. Geol. Survey, Thirteenth Annual Report, for 1884, p. 58; Final Report, vol. 2, 1888, p. 17).

Saint Croix river to become joined with the Tertiary Apple river. The Saint Croix, nearly as it exists at the present day, was thus an inheritance from the Ice age, beginning as an interglacial river perhaps some 40,000 years ago, and again during the final retreat of the ice-sheet, which here, according to estimates by Professor N. H. Winchell from the rate of recession of the falls of Saint Anthony, was about 8,000 years ago.

6. The erosion of the valley at the Dalles and for several miles from these gorges, both up and down the river, seems attributable in large part to preglacial streams flowing in opposite directions from a col of the Tertiary and early Quaternary watershed. These stream courses were made continuous by the interglacial Saint Croix. The gorge of the Upper Dalles has undergone further changes by late Glacial and postglacial stream erosion. Its walls have been much riven since the Ice age along the vertical joint planes, but they have suffered only very slight disintegration and decay through weathering.

7. Lakes Saint Croix and Pepin, besides Lac Qui Parle and Big Stone and Traverse lakes, are due to geologically recent and still progressing deposition of alluvium in these valleys, which were deeply eroded by the outflow from the Western Superior glacial lake and from lake Agassiz. The latest and present work of the Saint Croix river in both the Upper and Lower Dalles is to maintain very deep water there, due to the strong eroding current of the stream in times of flood, washing away the sand and gravel of its bed in these exceptionally narrow parts of the channel.

This paper attempts to give the broad outlines of the history of the Saint Croix river, and especially of its Upper and Lower Dalles, well known through these two states for their beautiful and even grand scenery. Other parts of the details of erosion in and near the Dalles remain for description and explanation in the following paper. To most visitors in the Interstate park, its peculiar rock sculpture to be next considered appears more singular and marvelous than the craggy gorges of the Dalles, the deep river, or the echoes from its cliffs.



MAP OF SAINT CROIX INTERSTATE PARK

showing location of giants' kettles

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 25-44, PL. 1 DECEMBER 6, 1900

GIANTS' KETTLES ERODED BY MOULIN TORRENTS

BY WARREN UPHAM

(Read before the Society June 26, 1900)

CONTENTS

INTRODUCTION

The most interesting feature of the Interstate park of Minnesota and Wisconsin, at the Upper Dalles of the Saint Croix river, consists in many large and small water-worn rock potholes, which are also, in their large examples, often called "wells." The languages of Germany, Sweden, and Norway give the name "giants' kettles" to such cylindric or caldron-shaped holes of stream erosion, which are everywhere characteristic of waterfalls and rapids, especially in crystalline rocks. Their Spanish name, remolino, used in the Republic of Colombia, has been recently advocated by Mr Oscar H. Hershey for adoption by geologists;*

* Science, new series, vol. 10, p. 58, July 14, 1899, followed by remarks of criticism or approval by others on pages 88, 187, and 298 of the same volume.

but either the common English term, potholes, or the German and Scandinavian designation, apparently alluding to mythical giants, seems preferable.

These potholes, occurring most numerously near the steamboat landing of Taylors Falls, Minnesota, at the central part of the Upper Dalles, and within a distance of 50 rods northward, are unsurpassed by any other known locality in respect to their variety of forms and grouping, their great number, the extraordinary irregularity of contour of the much jointed diabase in which they are eroded, and the difficulty of explanation of the conditions of their origin.

In view of the late Glacial confluence of ice currents there, known by the occurrence of drift on all the country eastward derived from the northeast and largely from the basin of lake Superior, while all the region westward is enveloped by drift from the northwest, with gravel and large masses of limestone from Manitoba, it is evident that the surface of the ice-sheet at its time of departure sloped downward from each side toward this area. The superficial line of boundary between the northeastern and northwestern drift, mapped for the Saint Croix Dalles area by Doctor Charles P. Berkey,* passes from south to north in coincidence with this part of the Saint Croix river. Beneath the ice-sheet during its later accumulation here, after the Buchanan interglacial stage, a subglacial brook flowed in the summers along the course of the interglacial Saint Croix. It probably ceased while the ice of that time attained its greatest area, depositing the Illinoian and Iowan drift; but when the ice was finally melting away, remaining here with only a depth of a few hundred feet, the same subglacial stream course doubtless received torrents plunging vertically down through crevasses and moulins. Such glacial waterfalls and the subglacial streams flowing rapidly away to a more deeply channeled avenue of discharge southward along the valley seem to have been the chief agencies of erosion of the potholes in the Interstate park and its vicinity.

A consideration of the diverse classes of streams which are capable of eroding potholes shows two modes of their origin dependent on glaciation. The purpose of this paper is to describe these "giants' kettles" at the Dalles and elsewhere near Taylors Falls, Minnesota; to compare with these, for aid in their explanation, other examples of their kind in many localities of North America and Europe, which are unquestionably of subglacial origin; to inquire what conditions were necessary for this result, and in what parts of a stage of glaciation they were apt to occur;

*Am. Geologist, vol. 20, pp. 355–369, with maps and sections, December, 1897. Compare my paper, "Changes of currents of the ice of the last Glacial epoch in eastern Minnesota," Proc. Am. Assoc. Adv. Sci., vol. 32, for 1883, pp. 231–234, and Geology of Minn., Final Report, vol. 2, 1888, pp. 409–417.

and to ascertain the relations of the glacial torrents forming potholes with the larger glacial brooks and rivers that produced kames and eskers.

Classification of Rock Potholes or Giants' Kettles

Potholes of Subaerial Waterfalls and Rapids

In all parts of the world the falls of rivers in cascades or rapids over granitic or other hard and enduring rocks wear portions of their rock bed into beautifully smoothed and gracefully or often fantastically curved forms, among which are frequently found bowl-like or cylindric holes. These range in dimensions from a diameter of a foot or less up to 10 or 15 feet or rarely more, with an equal or often greater depth.

In a few places such abundantly water-worn rocks, with potholes, are found where no stream now flows nor has existed since a lake hemmed in by the barrier of the departing ice-sheet had its outlet there, flowing over a col of the present watershed between independent hydrographic basins. This is one mode of stream action forming giants' kettles due to the Glacial period; but these kettles are not filled or covered by glacial drift.

Good examples of this class occur in New Hampshire at two localities where the watershed dividing the Merrimack and Connecticut River basins is crossed by railroads. The more northern and lower place, at Orange summit of the Northern railroad, had numerous potholes, some of which were partly and others entirely blasted away for the passage of the railroad. The most remarkable one, known as "The Well," was described by Jackson as 11 feet deep, 4½ feet in diameter at the top, and 2 feet at the bottom. It contained earth and round stones. Another locality of the same character is also reported by Jackson in Warwick, Massachusetts, "on the southern declivity of a bare ledge of gneiss forming the dividing ridge between the Ashuelot and Millers rivers."*

Giants' Kettles of Moulins and Subglacial Streams

The class of potholes more particularly considered in this paper depended directly on glacial action. They may be called, by way of distinction from those of subaerial streams, glacial potholes; or perhaps, by usage among geologists, the German and Scandinavian term, giants' kettles, may be restricted to this class of holes, bored in the bed-rock beneath glaciers or an ice-sheet by torrents of water falling through deep moulins. This name, moulin, coming from the French and meaning a

*C. T. Jackson: Final Report on the Geology of New Hampshire, 1844, pp. 113, 114, 282. Warren Upham, in Hitchcock's Geology of New Hampshire, vol. 3, 1878, pp. 64–66.

mill, is applied to a vertical tunnel, melted at first by the waters of the surface trickling into some very narrow crevasse that has just begun to open, until, after enlargement by this dissolving action, it receives sometimes a large stream, such as could not be waded, pouring with a thunderous roar down a cylindric shaft to the rock floor under the ice. But the streams that bored these potholes or giants' kettles were very small, and were only very scantily drift-laden, in comparison with the glacial rivers which formed the great esker ridges.

Rock exposures adjoining glacial potholes are often unmarked by other waterwearing; but in every present stream having falls and eroding potholes, larger spaces are irregularly worn and channeled. The rock kettles of moulin formation, found where no stream now exists nor can be supposed to have ever flowed except when the country was ice-enveloped, are the predominant or the only form of water erosion in their vicinity; but at the falls of ordinary streams, potholes are exceptional or a subordinate feature among more extensive grooving and other fantastically waterworn sculpture. It is evident, too, that glacial planation, ensuing after the moulin origin of the giants' kettles, although probably in many places effective to intensify this contrast, can not generally be its chief explanation, which is rather to be found in the protection afforded by the ice covering the rock contiguous to the base of the moulin. The rebounding water, indeed, welling up from one side of the rock kettle, may perhaps have usually flowed away, for its immediate exit, in an englacial tunnel, or at least with some drift between it and the rock. The conditions of erosion of the giants' kettles prevented or minimized contiguous waterwearing, which, on the other hand, is favored and predominant wherever potholes are made by subaerial streams.

Another way in which subglacial streams probably sometimes or often acted to erode potholes has been pointed out by Mr T. T. Bouvé* and Professor George H. Stone,† who well remark that the subglacial waters, after falling down the crevasses and moulin shafts, would flow rapidly away upon the surface of the bed-rock, and there might sweep past the mouths of potholes during the process of their erosion, supplying all the current needed for their further deepening by the whirl thus given to the water and stones at the bottom. For the largest and deepest of the giants' kettles, however, to be here noted as discovered in many localities of glaciated countries, I can not doubt that the pothole was cut down

* "Indian potholes, or giants' kettles of foreign writers," Proc. Boston Society of Natural History, vol. 24, pp. 219–226, April, 1889, with ensuing discussion by Warren Upham, pp. 226–228.

† "Glacial gravels of Maine and their associated deposits," U. S. Geol. Survey, Monograph 34, 1899, pp. 324–330.

exactly at the foot of a great and very deep moulin by its powerful descending torrent.

Potholes of subglacial erosion, whether bored just beneath a moulin or in or beside the pathway of a rapid stream flowing from it, may subsequently have become partly or wholly filled by till, the direct deposit of the ice-sheet, unmodified by water action, or such potholes may be completely concealed under a later general sheet of glacial drift. On the other hand, too, they may remain nearly or quite empty, having been so left, without drift accumulation, while the overlying ice disappeared.

Localities of Subglacial Potholes

INTERSTATE PARK OF THE SAINT CROIX DALLES

The northern part of this park and the adjoining southern part of the town of Taylors Falls are mapped on plate 1. The potholes are mostly on the western or Minnesota side of the Saint Croix, occurring plentifully on certain areas between Trap Rock street (the road to the steamer landing) and the river. These areas of their abundant development are comprised within a length of 50 rods from north to south and about 12 to 15 rods from east to west. With other tracts where single examples or a few occur, as west of this street, again on the Wisconsin side of the river, and again on a low rock hill in the valley about a mile north of Taylors Falls, not less than a hundred potholes are known in this vicinity. Many of them, however, are small, as a foot or less in diameter and one to five feet deep. The greater number were originally left empty, or with only a partial filling of rounded grinding stones, silt, mud, or peat, differing much in their contents. Others, mostly of small size, were found completely filled, and some were covered and hidden by a hard deposit of glacial drift, almost typical till.

The chief area of large potholes, worthy to be called giants' kettles, reaches from the steamboat wharf about 15 rods east-northeastward to Angle rock and about 20 rods northward, comprising only an acre and a half, within which space are all the very large and deep potholes known in the entire district. Counting the small and large holes, I found 30 on that area, including several so remarkable for their great diameter or depth, unusual form, or contents that they deserve to be separately described. The rock, like that of all the places having potholes in and near the Interstate park, is the very hard diabase trap of Keweenawan age, which here forms extensive outcrops, everywhere much divided by vertical and oblique systems of joints. Under the glacial and river erosion there has resulted a very ruggedly broken surface of rock cliffs and dells. Little or no drift and only few boulders have been left on the rock

tracts. Some of the potholes are on the slopes and tops of low cliffs, 5 to 20 feet above adjoining hollows. The height above the almost still river in the adjoining Dalles varies from 25 to 50 or 60 feet, rising highest northward.

In general, the rock surface has angularly broken slopes and cliffs, more or less glaciated, but since so weathered that the glacial striæ are effaced. Occasionally a little place, 10, 20, or 50 feet in extent, is smoothly waterworn; but more commonly the surface adjoining the potholes on this area and wherever they occur in this neighborhood, excepting in and near the river channel at the Saint Croix rapids, is roughly fractured or has been abraded only by the ice-sheet. The rim of the potholes, of whatever size, is usually abrupt, not merging with waterworn curving outlines of the adjacent rock, as at subaerial rapids and falls of our present rivers.

The giants' kettle of greatest diameter, which may be named "the caldron," is situated about 30 feet northeast from the east end of the wharf and 25 feet above the river. It is nearly circular, 25 by 27 feet in transverse diameters. Its sides descend vertically 8 to 12 feet, below which depth this kettle is filled with many angular rock masses from 1 to 5 feet long. Some of these may have been dislodged by frost action from a much-jointed cliff which rises at the northeastern brink of the kettle to a height of 10 feet above other parts of its rim. More probably, however, as in the case of the only other pothole observed to be similarly almost filled by rock masses, they are attributable to falls through the moulin, having previously been contained in the lower part of the ice-sheet as englacial drift.

Near the northern end of this area and 6 feet northwest of a foot-bridge, the most northwestern of a series of bridges which span little gorges and lead to Angle rock, is the other pothole mentioned for its contents of rock blocks and boulders. Its diameter is about 12 or 15 feet, and its depth, to be proportionate, should reach far below the surface of the many angular trap fragments, up to 3 or 4 feet long, which fill it to within 4 feet below the rim. No high nor fractured rock surface adjoining this kettle could yield its contents, which must therefore have come from the ice-sheet. They are unworn examples of the rock masses which in other instances, being less plentifully supplied, were gyrated in the bottom of the pothole by the torrent, wearing it deeper and grinding themselves to powder, until new masses of rock, falling in, took their places as the work of kettle erosion continued. Two very large kettles thus appear to have been interrupted in their formation by the abundance of their supply of grinding stones.

Honorable George H. Hazzard, the Minnesota commmissioner of the Interstate park, has partially cleared and sounded a very deep pothole situated 15 rods north-northeast of the wharf and about 5 rods east of the road (called Trap Rock street on the plat of Taylors Falls). The diameter of the mouth of this hole, not exactly circular, is 13 by 15 feet. Beneath several feet of water it was found filled to 15 feet below its mouth by peat and decaying leaves, branches, and trunks of small trees, but with no sand or gravel. By bailing out the water and excavating, the workmen went to the depth of 55 feet below the mouth, finding the diameter of the hole undiminished to that depth, its average being from 10 to 15 feet, with vertical cylindric form. A pole was then thrust 10 feet farther down, to a total depth of 65 feet, without reaching any grinding stones such as are almost invariably present at the bottom of these holes. The mouth being about 40 feet above the river, the bottom of this giants' kettle is thus ascertained to be more than 25 feet beneath the river level. The ratio of its diameter to its depth (so far as that has been probed) is as 1 to 5, showing thus a similarity with the deep cylindric giants' kettles near Christiania, Norway, but having a depth that exceeds them or any others known elsewhere.

It is exceeded, however, by its very close neighbor on the west, another pothole 25 feet distant, which has a diameter of 10 by 12 feet. This hole, filled by water to about 15 feet below its top, was sounded in the year 1878 by Dr Greeley Murdock, who since 1877 has been the principal resident physician of Taylors Falls. He found no bottom at the depth of 84 feet below the top of the rock at its mouth. It was an amusement of boys to thrust down tamarack poles 30 feet long into the water of this pothole, and it has now become partly filled with these poles and with driftwood, leaves, etcetera, that have been washed into it from a little marsh, a watercourse in times of river floods, adjoining it on the north and west. The mouth of this hole is mostly about 35 feet above the river, but its northeastern third falls off 8 or 10 feet—nearly to the marsh level. On the west the higher part of the mouth or rim is divided by only 5 or 6 feet of rock from a vertical descent of 12 feet of rock face or cliff bordering the marsh. It will be noticed that the ratio of the diameter to the known depth of this pothole is 1 to 7, but its entire depth has yet to be determined. It is known to extend about 50 feet beneath the surface of the river, which itself, near the angle of these Upper Dalles, is stated by Dr C. P. Berkey to be 160 feet deep.*

At a distance of about 40 to 70 feet northeast of "the caldron," the southern side of a rock knob is smoothly waterworn in two half cylin-

*Am. Geologist, vol. 20, p. 379, December, 1897.

dric, vertical, or in part slightly overhanging surfaces, as if halves of two very large potholes, each open toward the south, were joined, giving a combined diameter of 30 feet from west to east. The curved and cuspate rock face, rising 15 to 20 feet, from about 30 to 45 or 50 feet above the river, has variegated colors in different parts—reddish and black (by iron and manganese stains), a dark dull green (the natural color of the rock), bright yellow (patches of lichens), and, in some spots and streaks, light gray or even white (lichens, and efflorescence of carbonate of lime from water leaching through thin drift and the rock crevices). On account of their smokelike and fiery coloring, these halves of giants' kettles are called "the Saint Croix Fireplace." For the explanation of their erosion I can only suggest that here, as in places of moulin torrent action in Massachusetts and New York, effective erosion nearly as in a pothole of the largest size took place on a mural surface, with only ice, as we must suppose, to form the other side of the moulin. It is quite sure that they were worn as half-potholes instead of having undergone demolition and removal of the wanting part. On a smaller scale such mural segments of cylindric water-wearing are seen in several other places within this little area.

Close south of one of the foot-bridges leading to Angle Rock the narrow gorge, 15 to 20 feet deep, which the bridge spans, is enlarged, nearly like a great pothole about 15 feet in diameter, by the same cylindric water-wearing. The open passage of the gorge leading to the north is only half as wide, with roughly fractured walls due to nearly vertical joint planes. This place has been named by visitors the "Devil's Kitchen."

Again, a curious freak of the water-wearing is displayed by the "Bake Oven," a pothole 6 by 7 feet in diameter and 10 to 15 feet deep from its unequal rim. It is filled lower by soil and earth, forming a floor, on the continuation of which, by crouching, one may pass out eastward through an opening, waterworn under a thick roof of rock, to a lower space ten or 15 feet away. Only six feet of rock on the north side of the "Bake Oven" separates it from the hole that was excavated and probed to a depth of 65 feet, as before described.

Among the smaller potholes of this most interesting area, near the wharf, is one which is named the "Hourglass Well," situated about 10 feet northwest of "the caldron." Its diameter is about three feet at the mouth, and somewhat increases to the depth of 3 or 4 feet; it is then constricted, within two feet lower, to a diameter of only 18 inches, but widens again below to nearly three feet, the bottom being about eight feet below the highest part of the mouth. The constriction may have been due to a harder band of the rock which comprises successive lava flows. It should be noted, however, that a similar form of a pothole at

Gurleyville, Connecticut, described by Professor B. F. Koons,* seems to have been caused by varying conditions of erosion, there referable to a moulin torrent, rather than by inequality of hardness of the rock.

In a few instances the rock wall of a pothole intersects one, two, or three smaller potholes, which were partly worn away and merged with the larger one. A good example of such a compound rock kettle is situated 5 to 10 feet south of the very deep kettle sounded by Dr Murdock, the central hole there being five feet in diameter, with truncated holes 1 to 1½ feet in diameter.

With the large giants' kettles, interspersed upon the same area, are a greater number of others that measure a few feet, or only 1 or 2 feet, or even less than 1 foot, in diameter. These small kettles are mostly cylindric, with depths ranging commonly from twice to five times their diameter; but many are partially filled with sand, gravel, and rounded stones. Rarely a pothole displays a somewhat spirally grooved form, sweeping around once, or nearly so, in the whole descent, due apparently to erosion by the falling stream and stones after the hole had attained almost its full depth.

Farther north several small tracts, varying from 20 to 50 or 75 feet in extent, at heights of 50 to 70 feet above the river, including the highest part of the rock surface between Trap Rock street and the river, have many small potholes, varying from 3 or 4 feet to less than 1 foot in diameter, occurring mostly in groups of five to ten near together, but occasionally isolated. About forty were counted by me, and doubtless others were overlooked. On larger tracts of the adjoining rock, including its northeastern slopes toward the river, potholes are rare or entirely absent.

The most northern group is on a rock outcrop about 6 rods south of the northern boundary of the park. Within a space of 15 by 20 feet on this ledge are ten small potholes, from 4 to 10 inches in diameter, some of them cylindric, but others shallow, like a bowl. Their edges, as is usual elsewhere, are mostly cut abruptly into the rock, with sharp transition, at right angles, from the general rock surface.

The other potholes of this vicinity may be more briefly described. They are very scantily represented east of the river. One on that side, having a diameter of 3 by 4 feet at its mouth, with increase to 4 by 5½ feet at the depth of 5 feet, below which it is filled with earth, is situated about 20 feet northeast from the top of the head of the "Sentinel" or "Old Man of the Dalles." It is only 8 feet back from the verge of the cliff, which falls about 65 feet to the river.

---

* Amer. Jour. Sci., third series, vol. 25, p. 471, June, 1883.

Within 5 to 10 rods west of Trap Rock street and at the height of about 100 feet above the river several potholes from 1 foot to 3 or 4 feet in diameter, originally filled with drift, have been recently excavated under Mr Hazzard's direction. From these and from other potholes on their chief area before described multitudes of very smoothly worn stones have been taken, varying in size from small cobbles to nearly spherical masses 2 feet or more in diameter, while others, waterworn on all sides, but remaining oblong, measure 3 to 4 feet in length.

On the higher rock outcrops west of the park limits no potholes have been found. My search on the extensive tract of rock at and near the school-house, 200 feet above the river, detected only one spot definitely waterworn. This is about 30 feet west-northwest of the United States Geological Survey bench-mark of leveling (890 feet above the sea). It is a rounded hollow, about a foot in diameter, smoothly eroded by water to a depth of 6 or 8 inches, where no stream can have flowed since the departure of the ice-sheet.

About a mile north of all these localities a hill of the same trap rock rises between the railway freight-house of Taylors Falls and the river, its top being about 50 feet above the end of the railway, or 110 feet, approximately, above the river in the Dalles. Much of the rock surface on this hill is waterworn, and it has numerous small potholes, scattered, probably not less than 20 in all, mostly from 6 to 12 inches in diameter and about one foot deep. Two others of similar size were also seen on the northeastern slope of this hill, some 25 feet below its top and close east of the Saint Croix valley road.

In many other localities which have undergone glaciation potholes are found where they must be referred to moulin torrents and subglacial streams. Short notes of these, so far as they have come to my knowledge by observations, reading, and correspondence, are here added, that they may be compared with the foregoing in the Interstate park, which seem to me also referable to this phase of torrent work during the Ice age.

MAINE

Professor George H. Stone describes potholes on the island of Georgetown, adjoining the east side of the mouth of the Kennebec river.* One is near the level of high tide, and two others are about 60 feet above the sea. These are 4 to 6 feet in diameter and 5 to 10 feet deep, and others of smaller size occur in the same vicinity. The topographic relations show that no stream can have existed there, excepting when confined in

* "The glacial gravels of Maine and their associated deposits," U. S. Geol. Survey, Monograph 34, 1899, pp. 324–330.

an ice channel or tunnel. As it is known that the land there at the time of final recession of the ice-sheet stood about 230 feet lower than now, the pothole erosion seems probably referable to some earlier part of the Glacial period, before the continental subsidence restored a warm climate on the boundary of the ice and caused it to be melted away.

Another pothole, measuring about two feet in both diameter and depth, attributed by Professor Stone to glacial origin, is in Paris, Maine, on the side of a cliff. He thinks that the cliff caused a crevasse, into which a stream fell from the melting ice surface.*

Mr Charles Fry, of Boston, informs me, by letter, of a few small glacial potholes, occurring near together, about a foot or slightly less in diameter and of nearly the same depth, observed by him on the southeastern ridge of Green mountain, on Mount Desert island, at a height between 500 and 550 feet above the sea.

NEW HAMPSHIRE

Professor C. H. Hitchcock notes a pothole, 4 feet deep, on the top of Swetts mountain; one of large size on the southwest slope of Carrs mountain; and another, about two feet in diameter and depth, in Dunbarton, 125 feet above an adjoining valley. Another, described from my observations, is near the top of Beech hill, in New Hampton, about 600 feet above contiguous lowlands and lakes. This, like the one in Dunbarton, is called an "Indian mortar." Its diameter is 15 inches and its depth about two feet.†

Each of these potholes was quite certainly of subglacial origin; and at least the two instances on or near the tops of a mountain and a high hill seem explainable only by a torrent impinging on the rock at the bottom of a moulin.

VERMONT

Doctor Edward Hitchcock reported potholes at numerous localities in Vermont, far above any present stream, and in several instances high on the slopes or ridges of mountains. They are of different sizes, up to a diameter of 20 feet and depth of at least 25 feet.‡

MASSACHUSETTS

On the seashore in Cohasset, subglacial potholes have been described and figured by Mr T. T. Bouvé, showing vertical water-wearing to depths

*Ibid., pp. 327, 328.
†Geology of New Hampshire, vol. 3, 1878, pp. 249, 250.
‡Geology of Vermont, 1861, pp. 216, 217, 763, 930, 933.

of 5 and 10 feet.* Only one side of these holes is rock, with shallow rock basins at the bottom, the other side having been probably the ice-wall of the moulins through which the eroding torrents fell. Professor W. O. Crosby has also described this locality, referring the pothole erosion to the closing stage of the Glacial period.† At two other localities in Cohasset, Bouvé and Crosby report waterworn places on rock ledges where their origin must likewise be referred to a moulin or a subglacial stream.

Professor Crosby further supplies me the following notes, in a letter, concerning several localities of glacial potholes in Massachusetts.

At East Braintree a pothole, doubtless of subglacial formation, was discovered in excavating for a foundation, and later was destroyed by blasting. It was about 12 feet long, 3 to 6 feet wide, and 3 feet deep, shaped somewhat like a bathtub, but opening outward at one end, its smoothed sides there blending gradually with the irregular surface of the rock.

At Newton Upper Falls, on the abrupt southern slope of a high ledge of conglomerate, is a very distinct half of a pothole, some 2½ to 3 feet in diameter and 6 or 8 feet deep, to speak from memory. The appearance suggests at first that the southern half may have been split off by the action of the ice and the edges subsequently rounded; or possibly the pothole was formed between the rock on one side and the ice on the other. At the bottom the waterworn surface curves and runs off horizontally along the face of the ledge for several feet, gradually fading out.

Several small and large glacial potholes, up to 8 or 10 feet in diameter, are worn in granite ledges close to the Fitchburg railroad between Roberts and Stony Brook stations. They are nearly filled with drift, and their depth therefore cannot be stated.

In the village of Clinton, a very perfect, but small, glacial pothole, about 1 foot in diameter and 2 feet deep, is eroded in a beautifully glaciated slate ledge.

During the work on the Wachusett reservoir, at a point about a mile southwest of Clinton, two potholes were temporarily exposed last summer on the lee slope of a prominent ledge of contorted phyllite, which rises above the surface of a widely extended glacial sand plain. They were 1 to 2 feet in diameter and of corresponding depths.

At West Berlin station are several small potholes, which Professor Crosby attributes to erosion by the outlet stream of the glacial lake

* "Indian potholes, or giants' kettles of foreign writers," Proc. Boston Soc. Nat. Hist., vol. 24, 1889, pp. 219–226; with discussion by Warren Upham, pp. 226–228.

† "Geology of the Boston Basin" (Occasional Papers of the Boston Soc. Nat. Hist., iv), vol. 1, 1893, pp. 148–159.

Nashua, formed in the basin of the Nashua river by the barrier of the departing ice-sheet.*

CONNECTICUT

At Gurleyville, on the east side of the Fenton river, a group of glacial potholes, at the height of 98 feet above the river and 42 feet above the highest terraces of valley drift in the vicinity, is described by Professor B. F. Koons, before cited. The one which remains entire, on being cleared from its contents of water and stones, was found to be 6½ feet deep, with a shorter diameter at the surface of 3 feet and 9 inches and a longer diameter of 4 feet and 3 inches. The author notes its unusual form, somewhat like an hourglass, and its relationship to the group as follows:

"About 2 feet above the bottom the diameter is reduced to about 30 inches, and then widens again below this point, leaving a horizontal ring at the narrow place. What can have been the cause of the forming of the ring at this point is not entirely evident. If the rock were horizontal, it would seem that a hard layer in the rather uniform gneiss would account for it; but, since the rock dips at an angle of about 30 degrees and this projecting ring is horizontal and only a couple of inches thick, I find myself at a loss for an entirely satisfactory answer.

"This pothole is near the edge of the cliff, and the remnants of three others appear upon the face of it, and one of these three shows a diameter of 9 feet and a depth of 6. All are within a few feet of each other, a couple of them separated by a thin partition only." †

Professor James D. Dana mentioned the occurrence of potholes in the gneiss of islands off the Connecticut coast and others on Thimble island, in the bay of Stony creek.‡

NEW YORK

The earliest published information, so far as I have learned, of potholes in America attributable to moulin torrents was given by Doctor Ebenezer Emmons, in 1842, describing and picturing a very large pothole in Antwerp, Jefferson county, New York, and noting others near Hammond, in Saint Lawrence county. The Antwerp pothole is about three-fourths of a mile south of Oxbow village, and has a height of about 100 feet or more above the Oswegatchie river, which bends in its course at Oxbow, thus giving the name of that village. Only one side of this pothole remains. Very probably, as at other places already mentioned, only half of it was worn in the rock, the other half having been the ice of a moulin. The hole is from 24 to 30 feet deep, with a diameter of 12 feet

* "Geological History of the Nashua Valley during the Tertiary and Quaternary Periods," Technology Quarterly, vol. 12, December, 1899, p. 318.

† Amer. Jour. Sci., third series, vol. 25, June, 1883, p. 471.

‡ Manual of Geology, fourth edition, 1895, p. 949.

in its upper part and 14 feet below. On a later page of the same report, in a discussion of the drift and striation of the northeastern part of this state, Emmons wrote of "the numerous potholes in ledges of rock now distant from any stream and far above all the creeks in the region." *

In southeastern New York potholes which may be of glacial origin have been described by Doctor N. L. Britton in the Bronx valley, 2 to 3 miles north of Williams Bridge, two having depths respectively of about 9 and 10 feet,† and others were noticed by Professor Oliver P. Hubbard in the Hudson valley, opposite to the town of Catskill.‡

PENNSYLVANIA

The most remarkable known of these giants' kettles, whether we consider their size or the manner of their occurrence and discovery, are two found in 1884 and 1885 in Lackawanna county, Pennsylvania, about three miles northwest of Archbald. As described by Mr C. A. Ashburner, the Archbald potholes are 1,000 feet apart and were both discovered in coal mining, their bottoms being in the coal bed. When the drift filling the one first discovered was cleared out, it was found to be 38 feet deep, with a diameter of about 15 feet at the bottom, increasing to a maximum of 42 feet and a minimum of 24 feet across its top. The second pothole, of similar basal diameter in the coal bed, had not been cleared of its drift contents, but it is known, from the leveling and test-pits or borings of the mining company, to have a depth of about 50 feet in the rock, with a covering of 15 feet of drift above.§

IDAHO

A very interesting series of glacial gravel deposits in north central Idaho, resting along a part of its course on a rock bed that is much waterworn and marked by potholes, is described by Professor George H. Stone. It is a short distance south of Elk City, on head streams of the south fork of the Clearwater river. The area was covered during a part of the Glacial period by a piedmont ice-sheet or broad glacier, deploying westward from the Bitter Root mountain range, nearly as the present Malaspina ice-sheet of Alaska is spread out between Mount Saint Elias and the sea. These gravel deposits belong in the same class with the prolonged series of esker or osar ridges and gravel plains which are so grandly developed in Maine and in Sweden, and of which occasional examples occur also, although of less extent, in nearly all broadly gla-

* Geology of New York, part ii, survey of the second geological district, 1842, pp. 410, 411, 424.

† Trans. N. Y. Acad. Sci., vol. 1, 1882, pp. 181-183; Amer. Jour. Sci., third series, vol. 25, p. 158, February, 1883.

‡ Trans. N. Y. Acad. Sci., vol. 9, 1890, p. 3.

§ Geol. Survey of Pa., Annual Report for 1885, pp. 615-625, with a map, sections, and two plates (views from photographs of the first pothole when cleared out for use as an air shaft).

ciated districts. Beneath the ice-walled esker river the bed rock was worn and sculptured with hollows and giants' kettles. Of the locality where this has been made known by gold mining, Professor Stone writes as follows:

. . . "On the hills between Red Horse and American rivers the placer miners have washed away the overlying gravel. The rock beneath the gravel is very much smoothed and polished, but is very uneven, containing many rounded depressions, bowls, and potholes up to five feet in depth. Evidently here was a broad river that flowed up and over hills and valleys. That it disregarded the surface forms of the land proves that it was enclosed between walls of ice. The stratification is not arched in cross-section like that of the osar proper, but is horizontal, like the deposit I have elsewhere described as the osar plains of Maine."*

NORWAY AND SWEDEN

Giants' kettles referable to moulin waterfalls and subglacial stream erosion are known at many localities in Norway and Sweden, according to S. A. Sexe, Brögger and Reusch, Baron Gerard De Geer, and others.

In the close vicinity of Christiania numerous giants' kettles have been discovered and cleared of the glacial drift and water-rounded stones which filled them. The locality of greatest interest is Kongshavn, a southeastern suburb on the shore of the Christiania fjord, where, between the lines of low and high tide, a glacial pothole eroded in gneiss was found, on the removal of its drift contents, to be 16 feet deep, with a diameter of 5 feet. Another pothole, from which the drift was excavated under Professor Kjerulf's direction, measures 34 feet in depth on one side and 44 feet on its higher side, having a nearly cylindric but somewhat spiral or rifle-like form, 8 to 12 feet in diameter. The altitude of its mouth is 90 feet above the sea.†

Taking up the question of the probable epoch or stage of the Ice age in which the Christiania giants' kettles were eroded, we are confronted by the occurrence of marine shorelines and shells in deposits overlying the glacial drift, which demonstrate that during the time of the glacial recession there the land was depressed about 600 feet below its present height. It is impossible to ascribe the moulins and potholes to torrential agency so far beneath the sealevel, and consequently they must belong at Christiania to the earlier time of high land elevation and snow and ice accumulation.

THE GLACIER GARDEN, LUCERNE

Excavation in the glacial drift for a cellar, in the year 1872, first revealed a part of the very admirable group of giants' kettles which is now

* Amer. Jour. Sci., fourth series, vol. 9, pp. 9–12, January, 1900.

† "Giants' kettles at Christiania," by W. C. Brögger and H. H. Reusch, in Quart. Jour. Geol. Soc., London, vol. 30, 1874, pp. 750–771.

one of the chief attractions of sight-seers in Lucerne, Switzerland. This town, visited by the writer in 1897, is in many respects the most fascinating one for tourists in the Alps, and the most convenient for many neighboring excursions, as to mounts Rigi and Pilatus, and the sail on the wildly picturesque and historic Lake of the Four Forest Cantons. The Glacier garden, containing the giants' kettles, is about 100 feet above the lake, and is only a few steps from the Lion monument, designed by Thorvaldsen, which was chiseled from the solid rock fifty years earlier (in 1821). Thirty-two potholes of moulin torrent erosion are counted in the garden, occurring irregularly grouped upon a remarkably furrowed, waterworn, and glacially striated rock area about eight rods long and four rods wide, which was originally so drift-covered that its wonderful torrential and glacial sculpture was concealed. The covering of soil and drift has been removed since 1872, and many rounded stones, which served as grinders rapidly whirled around by the falling waters, from those of small size up to others of huge dimension, five feet or more in diameter, have been removed with the gravel, sand, and clay that filled these rock kettles.

The largest pothole of Lucerne, on the northwest border of the group, has a diameter of 26 feet and depth of 31 feet. Its southern side overhangs, probably because the northwardly flowing current of the overlying glacier carried the moulin slightly forward while the rock erosion was taking place. The movement was least at the base of the glacier, and increased differentially upward. The moulin therefore became inclined, and discharged its torrent somewhat backwardly into the rock kettle, hollowing it thus with an overhanging wall. The same feature is observable in others of these potholes, and several of them display spiral wearing. In some instances the potholes have irregular and composite forms, showing apparently that successive and independent moulins, probably of different years, contributed to their erosion. They range in size from the largest to others 9 or 10 feet deep and 4 or 5 feet in diameter, and to small cylindric or hemispherical kettles only 1 or 2 feet deep.

It is also to be noted that the rock at two or three places is waterworn in broad and somewhat crooked grooves, varying in depth to 6 or 7 feet, and extending 20 or 30 feet in length, where the moulin torrent was less concentrated and more variable than usual; or, more probably, these grooves may have been made by a very inclined and powerful englacial and subglacial stream there impinging on the rock floor. Perpendicular potholes of the usual form, but of small size, occur occasionally in the grooves. It is especially noteworthy, both here and in other localities of Europe and America, that generally the edge or lip of the giants'

kettles, whether large or small, is abruptly cut in the rock surface, perhaps sometimes because of their partial removal by glaciation subsequent to the moulin erosion. They seldom have a flaringly curved mouth, such as more frequently characterizes potholes seen at the present time in the process of erosion by cascades in brooks and rivers.

Conditions of Erosion of Giants' Kettles

According to these observations and records of glacial potholes in their best known localities on two continents, it seems to me most probable that the time of their excavation in many cases was the early part of the Glacial period, or some stage of glacial extension, when the ice-sheet was being formed upon the land by snowfall. On any hilly country the ice must have attained an average depth somewhat exceeding the altitude of the hills above the adjoining lowlands before any general motion of the ice-sheet could begin. During the process of slow accumulation of the ice-sheet, the summer melting upon its névé surface would produce multitudes of rills, rivulets, and brooks, which might unite into a large stream; and this, pouring through a crevasse and melting out a cylindric moulin, might fall perhaps 100 or 200 feet or more on a moderately hilly region, but probably sometimes 500 feet or more on a mountainous district, while yet the ice motion, though sufficient to permit the formation of the crevasse, might not have gained a definite current to carry the crevasse, moulin, and waterfall away from the spot where they were first formed. We may thus explain the continuation of a glacial waterfall in one place while it was excavating one of these giants' kettles.

After the ice-sheet acquired a current because of the greater thickness and pressure of its mass, such deep cylindric excavations in the bed rock could not be made, because the ice and moulin were in motion; and during the final dissolution of the ice-sheet it seems probable that its receding border had generally steeper gradients and consequently even more rapid motion than during the culmination of the Glacial period.

Moreover, the streams formed on the surface of the ice-sheet by the summer melting before it was so thick as to have motion would be free from drift or any load, excepting what might be derived from projecting hills or mountains, so that their waters could readily find a way through crevasses, forming potholes in the rock beneath by means of detached blocks from the same rock bed, and thence flowing away in subglacial courses. On the contrary, the superglacial streams during the departure of the ice, which then became more or less covered with the previously englacial drift, laid bare by ablation, were heavily freighted with the

gravel, sand, and clay of the modified drift, which must have soon choked up the passages wherever these drift-laden streams found crevasses, causing them to flow in superficial channels walled and underlain by ice, until, near their mouths, the ice was melted through to the ground and kames and eskers there received the coarser part of the river's burden.

In some places, however, we may better ascribe the moulin torrents forming giants' kettles to the closing stage of glaciation, at the time of final melting of that part of the ice sheet, because this appears to be strongly indicated by a general lack of drift deposits to fill the potholes, as in the Interstate park, most particularly described in this paper. If we can affirm for such tracts of the ice margin, while it was finally melting away, a nearly or quite stagnant condition, allowing a moulin to remain without advance during a series of years, it seems to account for these deep but mainly empty potholes more satisfactorily. Therefore I am inclined to refer the giants' kettles of this park in the Saint Croix valley to the latest recession of the ice-sheet from this area.

The rock gorges of the Lower and Upper Dalles seem to me, as noted in the preceding paper, to have been eroded by the river, even to a great depth beneath its present level, during the long Buchanan interglacial stage or epoch of the Ice age. At the same time a wide reach of the valley, now partly occupied by Thaxter lake, was eroded between these narrow gorges, and a gradually descending ravine was channeled at the east side of the Upper Dalles, slightly north of the angle.

During the later and long envelopment of this area for a second time by ice, drift may have been deposited in this valley, on an average, to a nearly similar amount as on the adjoining higher ground—that is, to depths of 10 to 20 feet, more or less—but its scantiness on the trap outcrops, and the many empty potholes, suggest that there very little drift had accumulated. When the ice was melted back so far as to leave the valley open above the Upper Dalles, its next mile northward to the Saint Croix rapids became filled, to the height of about 60 feet above the present river, by a sand and gravel plain, now forming a terrace on each side, and in part, especially on the east, by coarse boulder drift. Upon these deposits the river ran during many years, smoothly wearing the boulders of its bed, which, as the river cut down its central channel to the present level, have fallen in great numbers from the upper part of the river bank to the water's edge.

Glacial Streams of Giants' Kettles and Eskers compared

The rate of erosion of the giants' kettles, referred in most localities to a stage of incipient glaciation, and the rate of formation of kame knolls

and hills and esker ridges during the wane of an ice-sheet, were surprisingly rapid, in comparison with the generally very slow rates of geologic action. Watch the artificial processes of granite and marble abrasion and polishing, and there will be no need to doubt that the largest rock kettle of the Interstate park, of Archbald, Christiania, or Lucerne could be hollowed out during the warm months of even a single year by a stream 20 or 50 feet wide, and 2, 3, or 5 feet deep, falling down a moulin 200 or 500 feet deep, and well supplied at the bottom with grinding boulders of granite and other very hard rocks. Crevasses and moulins would be formed in successive years at nearly the same situation, thus producing such a profusely kettled surface as in the Interstate park or the Glacier garden.

Although we have been able to cite many localities of giants' kettles due to moulins and their waterfalls, they are far exceeded in numbers by the gravel and sand deposits called kames and eskers, which are attributable mostly to larger glacial streams. From my observation, it seems clearly within the limits of truth to estimate that we have records of hundreds of kame and esker streams for every one that is known to have formed a giants' kettle by plunging down a moulin or by flowing in any cascade or rapid along its subglacial passage.

If the retreat of the ice-fields under ablation was so rapid as a tenth of a mile yearly, which was apparently its rate near Stockholm, according to observations by De Geer, or about half a mile each year during centuries, as was probably true of the area of the glacial lake Agassiz and the vast plains of the Saskatchewan and Winnipeg country, we can not doubt that the most massive esker ridges, as in Sweden, or in Maine, and the highest kame hills, as the Devil's Heart hill, 175 feet high, in North Dakota, could be formed within a few years for any single section, or perhaps even within one summer for the great kame mentioned. Some of these gravel-depositing rivers, as shown by the widths of esker ridges and plateaus, were two to five or ten times larger than those of the moulins and rock kettles.

The streams flowing in the summers from the border of the ice-sheet were doubtless of larger size and greater numbers during the final disappearance of the ice, when they formed the kames and eskers, than at any previous stage of the Glacial period. Many of the giants' kettles, if not all, are clearly referable to an early or intermediate stage. For example, they are found in Maine and in Scandinavia on coastal tracts that were depressed and submerged beneath the sea to the depths of hundreds of feet when the ice was finally melted away, as is demonstrated by the relations of the glacial drift and the overlying marine deposits, which contain molluscan shells such as now exist only in the

cold waters adjoining glaciers in the arctic regions. As erosion of the bed rock cannot be supposed to have occurred at the bottom of a moulin extending so far below the sealevel, we are compelled to ascribe these glacial potholes, some of them small and others of great diameter and very deep, to some earlier part of the Ice age. I have thought them referable to the time of great continental uplift, proved by submerged valleys, when a severely wintry and snowy climate, resulting from the high land elevation, caused these great areas to become first enveloped by ice-sheets. Afterward, wherever glaciation was interrupted and again renewed, previous to the general subsidence of the land which terminated the Glacial period, moulin torrents might erode potholes during the later stage of snow and ice accumulation. Near the coast and at low levels they would lie under the sea during the departure of the ice-sheet, and the washing of sea waves may in some instances have removed the drift with which they had been filled.

While it is most probable that in some localities, as the Interstate park, giants' kettles originated during the final retreat of the ice, they seem predominantly referable to the beginning of glaciation or to a stage of its renewal. In many places, therefore, the bed rock containing them would be deeply worn away by ensuing glacial erosion, the potholes being spared only where they were protected by deposits of drift or where the rock was little worn by the later glaciation. According to this view, the infrequence of discoveries of these records of moulin waterfalls has been due to their present concealment by drift and elsewhere to their erasure by glacial planation of the bed rock. Kames and eskers, on the other hand, belonging to the time of glacial recession and to the surface of the drift, have been abundantly preserved, testifying of the formation of more numerous and larger streams fed by the glacial ablation and rains and carrying much sand and waterworn gravel.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 45-56, PLS. 2-5 · DECEMBER 21, 1900

VOLCANIC PHENOMENA ON HAWAII

BY C. H. HITCHCOCK

(Read before the Society June 26, 1900)

CONTENTS

HISTORY OF THE ERUPTION

The volcanic phenomena observed on Hawaii and described in this paper relate to the recent eruption from Mauna Loa and the presence of ash beds.

On June 20, 1899, a very distinct earthquake shock was felt at Wailiilii, my temporary residence, 23 miles from Hilo, 8 from Kilauea, and 24 in a right line from the place of outburst. It was at 7.40 p. m., and lasted about a quarter of a minute. At about the same hour two shocks were observed at Hilo, one of them quite severe. None were noticed at the Volcano house by Kilauea, which is 18 miles from the place of outburst. A few days later another shock was felt; also on July 11, and perhaps later. It is natural to believe that these earthquakes had a direct connection with the eruption, especially as they were particularly manifested along a supposed axial line of lava accumulation.

On the first day of July the manager of the Egan coffee plantation, 21 miles from Hilo, saw a light above the top of Mauna Loa, or the pit Mokuaweoweo. On the morning of July 4 this light was quite conspicuous from both Hilo and Punaluu. Early July 5 there came an outburst of liquid lava from a point in the ridge 6 miles northeasterly from Mokuaweoweo and 30 from Hilo. It was best seen at Kilauea. The people there had been expecting an eruption in their own volcano; hence when early in the morning they heard a great noise like thunder and observed a flash of light they looked to see commotion in Kilauea. In this they were disappointed, and, looking in a contrary direction, saw the beginning of the flow of 1899 from Mauna Loa. Fountains of liquid fire spouted hundreds of feet high, at an elevation of about 11,000 feet above the sea. The place of discharge proved to be near to but higher than the source of the flow of 1880, and not far away from the terminal cones of the discharges of 1823, 1843, 1852, and 1855.

Parties commenced immediately to travel to the source of the flow, contrary to the report sent east by the press that people were fleeing for their lives, abandoning their plantations to the fiery flood. Citations will be made from the accounts given by Professor Edgar Wood,* C. W. Baldwin,† Professor A. B. Ingalls,‡ and the Honorable W. R. Castle,§ the dates of their visits having been July 11, 12, 13, and 16, respectively. I visited the place of the outbreak in 1883, and speak of it in my notes as a region of indescribably rough lava, both "aa" and "pahoehoe," black, yellowish, and brown. Our horses were left some distance behind, as the blocks of lava were too large and rough to be comfortably traversed by them. The crater of the Kau part of the 1880 flow was a mass of black and red lapilli. The adjacent terminal crater at the head of the Hilo stream still emitted heat and vapor, more than two years after it started. The 1899 flow began its course near the source of the Hilo stream of 1880, and more than two miles above the beginning of the eruption of 1852. By July 5 two fountains were in operation, at about 11,000 and 10,800 feet elevation, and nearly a mile apart. A week later the upper one had become only a smoky chimney, while a third cone was active near the second. The lava streams from the two openings united and then flowed northerly, directed toward Mauna Kea. Plate 2 represents the aspect of the cone and flow as photographed by Davey July 13, 1899. Masses of stones and clots of lava were seen to be thrown out with the liquid lava. C. H. Kluegel, chief engineer of the Oahu Railway Company, drew a rough sketch of the cone, with its discharge, estimating the stream to be

* American Geologist, Nov., 1899.
† Hawaii's Young People, Feb., April, and May, 1900.
‡ Hawaiian Annual for 1900.
§ Hawaiian Gazette, July 25, 1899.

TERMINAL CONES OF THE MAUNA LOA FLOW OF 1899

60 feet wide, the fall 80 feet in the first 400 feet of descent, the velocity 40 feet per second, and the depth 10 feet. "There is a continuous and somewhat regular flow of lava, with explosions at intervals of one-half to one-eighth second. The lava is thrown up almost continuously 150 feet and occasionally 250 feet high," says Kluegel. For several days, when the air was free from clouds, the fountains of lava were beautifully exhibited from the Volcano house both day and night. The fountain constantly shifted its position, and when nearest the edge of the cone the falling clots resembled spangles of gold in the night-time. Plate 3 is a reproduction of this scene, July 16, as painted by the artist, D. Howard Hitchcock. Plate 4 shows the condition of things on July 19, as photographed by C. C. Langill, whose camera was evidently situated on the third cone, the one shown on the left of the principal vent in plate 2. It proves, like plate 3, the ejection of stones and vapors from the orifice.

Professor Wood's Observations

Of the appearances July 11 Professor Wood writes thus:

"There were two principal live cones, one much more active than the other. Great masses of rock at a white heat were being hurled high into the air. These were probably pieces of the crater wall. Sometimes quantities of molten lava were blown out; at other times a mixed material in which there was a great deal of sulphur. This molten matter would sometimes be thrown to the height of 200 feet. Almost continuously it went higher than 100 feet. This process was going on with almost no interruption, while at intervals great volumes of smoke poured forth from the edges of the crater. The principal cone was about 150 feet high on the north side. The other sides were considerably lower. A deep crack between 30 and 40 feet wide ran off in an easterly direction. The cone itself was nearly, if not altogether, 200 feet across the top, filled with lava at a white heat, never still, ever leaping, sometimes higher, sometimes lower, ever falling back upon itself or spilling in flakes over the side of the cone. Explosions were numerous, almost continuous, while all the time the rushing, roaring sound of the fire fountains filled the air. Wonderful as was this sight, the view of the river of fire was not less so. It rushed through the opening at the speed of a race-horse, and, plunging over a fall of perhaps 15 or 20 feet, went madly through a deep channel down the side of the mountain. It rushed along with such force that the surface was marked with undulations like the waves of the sea."

C. W. Baldwin's Observations

The visit of the brothers C. W. and E. D. Baldwin followed that of Professor Wood, not far from the 12th of July. From a prolonged sketch the following items are gathered: The whole region about the active cone was a tough network of new flows, and they appeared to have gone in every direction. The sounds increased as we came nearer, but they

were only such as would come from a violently tossing mass of li matter. They did not notice the explosions that were reported l The third cone is only a stone's throw from the latest active one. lava which was thrown into the air went up in a red-hot mass, but tur black as it fell. Pumice was noted among the products of the erupt There were two or three light earthquake shocks when the flow stop

Professor Ingalls' Observations

Professor A. B. Ingalls reached the eruptive cones by way of Mol weoweo, starting from Kona, on the west side of Hawaii. The r was more difficult than the approach from the Kau side. He found upper cone to be "merely a smoldering heap, while the lower and ther one was the real fountain-like crater." . . . The upper "had the shape of a truncated cone, with a deep gash on the upper s in which we could plainly see hot rock. From this vent, as well as f the top of the cone, great volumes of sulphurous steam poured fo The trade-wind carried these fumes over the southwest side, compel us to pass along to the north and east of this pile on our way dow the spouting crater." On the north there was a deep layer of spo like pumice, which impeded progress, like deep sand. The lava flowed down as "aa," and the same clinker material filled the re between the cones. "The display was a continuous lava fountain w out cessation. Rocks were ever rising from or falling back into mighty cauldron, and yet the shapes of the pieces and the general st ture and outline of the masses as they stood for an instant before c mencing to fall back into the seething pit was never twice alike; so the clouds of vapor." At one time it was a dome pinnacled by a col of flame: at another, an Eiffel tower stood in outline for an instant then fell back in a heap of ruins.

On the return Professor Ingalls and his party were in danger of b enveloped in and strangled by the sulphurous fumes.

Statements by W. R. Castle

The estimates given by the Honorable W. R. Castle agree with t already quoted. At night an occasional heavy thud gavè eviden the proximity of a live volcano. He says:

"The cone is probably 250 or 300 feet across the top, and is filled with a res surging mass of white-hot lava, always leaping into the air, sometimes rising height of 200 feet. Explosions are continuous. Now and then a heavy vo of white smoke is literally shot into the air. It is always rising and rolling a

TERMINAL CONE IN ACTION, JULY 19

covering the island with a thin, vapor-like pall." . . . "In two seconds an acre of ground would be covered a foot deep with lava." . . . "Stalactites formed before the rush wholly dropped, and in a moment they could be seen hanging from the roof, still dripping, but all bent downstream."

Flows along a Ridge

The 1899 and older flows started from near the crest of a ridge or watershed and extend from the summit northeasterly, including Puu ula ula and Kulani. The points of eruption are so near the crest that a slight change in its position will cause the lava to flow toward the north (Kea) or toward the south (Kau). The 1899 flow was thought at one time to be moving south, but it finally discharged north.

The flow of 1880 moved in three directions—first, toward Mauna Kea for about three weeks; second, starting a mile lower down the ridge, directed toward Kau for 10 miles, averaging a mile in width; third, commencing half a mile still lower down, moving first toward Kea and then sweeping around to the right toward Hilo, a distance of 45 miles.

The 1899 flow continued to run till July 26, having a length of 15 miles and a width of about a mile along its lower course. It consisted chiefly of "aa."

Fissures

Extensive fissures follow the crest of the ridge, from one or more of which the latest discharges have proceeded. Some of them may be followed for miles, both up and down, but none have been reported immediately adjacent to Mokuaweoweo. Corresponding crevices have been described as pointing toward the summit at Waiohinu, Kahuku, Kealakekua, and other localities, so that we have the phenomenon of a central elevated pit with immense fissures directed radially from it, and all the eruptions known are located on some one of these fissures.

Atmospheric Phenomena

A column of smoke constantly arose from the points of ejection, visible on all sides. It expanded as it arose, and closely resembled the so-called "pine tree" shown on photographs of eruptions from Vesuvius. The northeast trade-wind does not reach the altitude of the outbursts; hence the vapors may arise vertically and be spread out on all sides like an enormous umbrella. While the south wind blew the smoke cloud reached Honolulu, on Oahu, 200 miles distant. Some people observed a distinctly sulphurous odor, while one gentleman asserts that he had

been distinctly struck in the face by particles of the volcanic dust. July 17 the steamer "Mariposa" observed this smoke, some 600 miles to the northeast. Similarly the officers of the "Morning Star" found themselves unable to take the customary observations for latitude at an equally great distance to the southwest. The diameter of the area obscured must have considerally exceeded 1,200 miles, as the observations reported were much to the north of the major axis.

It was also interesting to observe the presence of an enormous cumulus cloud directly over the crater of Mokuaweoweo. This was developed by the rising of heated vapors from the summit crater coming in contact with a cooler atmosphere.

Mokuaweoweo

Plate 5 is copied from photographs taken by Davey of the appearance of the pit Mokuaweoweo July 13. Concerning the appearances Professor Ingalls writes:

"The floor of the crater was of black lava, to all appearance precisely like that of Kilauea, with a few rough patches here and there which I believe was 'aa.' Extending in a direction roughly parallel with the west wall, from the talus at the base of the lower terrace at the north pretty nearly to the gap in the south, there stretched a crack in the crater floor, all points of which lay slightly west of the medial north-and-south axis. From various places along this fissure rose up nearly all the signs of the existence of volcanic fires beneath, these evidences being sickly jets of steam, rising in such a manner as to suggest no urgency from below; also at the bottom of the southwest wall the talus appears to be undergoing a transformation into sulphur banks. There was nothing in the appearance of this summit crater to warrant an assumption that at this very time, at the depth of 3,000 to 3,500 feet below the level of this floor, there was a genuine volcano in terrific eruption." *

Two Kinds of Eruptions

The history of volcanic action on Mauna Loa indicates two kinds of eruption. Most of them have presented phenomena of this nature: After premonitory earthquakes, the first manifestation of activity is the sudden appearance of much molten lava in the top crater, Mokuaweoweo, which is shown by the light reflected on the sky. Often the finest fountains of fire are displayed at the summit. Within a very few days there is a fracture in the side of the mountain, accompanied by noise, and lava flows freely, as if from hydrostatic pressure, and the liquid disappears at the summit. So far as known, all the discharges from altitudes of 4,000 feet or less below the surface of the fused lava have made their

* Hawaiian Annual for 1900.

[redacted]

way through limited orifices, and have flowed down the mountain for weeks or months.

The other kind of eruption was manifested in 1868 and 1887, near the south end of the island. It commenced with a light at the summit, but discharged on a long line of vent from 10,000 to 12,000 feet below the fused pool in Mokuaweoweo. The outburst was preceded by violent earthquakes, and continued to flow only two or three days, the amount of the discharge being approximately equal to that sent out at the higher level. The eruption of 1899 clearly belongs to the first category.

Areas of Weakness

Two areas of weakness are indicated: the first at the southwest base of the mountain, where the violent discharges have come to the surface; the second is a considerable tract on the northeast slope, which carries the sources of the flows of 1823, 1843, 1852, 1855, 1880, and 1899. They bunched together from 9,000 to 11,000 feet above the sea and to the northeast from Mokuaweoweo. Figure 1 * exhibits roughly their positions and comparative importance. Probably a dozen terminal † cones are scattered over this area, and they are plainly visible 20 miles away. The hill Puu ula ula is the most prominent elevation in this tract, and it is one of the signal stations of the Hawaiian Trigonometrical Survey. It was incorrectly located on the early maps, and the propinquity of the terminal cones was not observed till the effort was made to fix the precise position of the latest flow with reference to the others.

The Mauna Loa Dome

Mauna Loa is an elongated dome, 74 by 53 miles in the two diameters, as measured at the sealevel, and 13,650 feet in altitude. Sometimes it has been spoken of as extending downward more than 16,000 feet farther to the level of the submarine plain on which the whole archipelago is based. That would present a cone 30,000 feet in altitude, and we can imagine it to contain a tube through which lava has welled up from this enormous depth. Perhaps the recent discovery of the Tertiary age of the foundations of Oahu may suggest that the base of the cone rests on sedimentary material—a low island—thus avoiding the hypothesis of an ejection built up from the sea bottom by means of volcanic debris. The

* The map is compiled from data afforded by Professor W. D. Alexander, chief of the government survey.

† This term has been commonly applied to the small craters built up from the several orifices of the different flows.

existence of such a Tertiary base is yet to be proved for Hawaii except in a theoretical way.

The surface of this dome is covered by a multitude of lava streams—irregular, straggling, inky rivers—which are well seen from Mauna Kea,

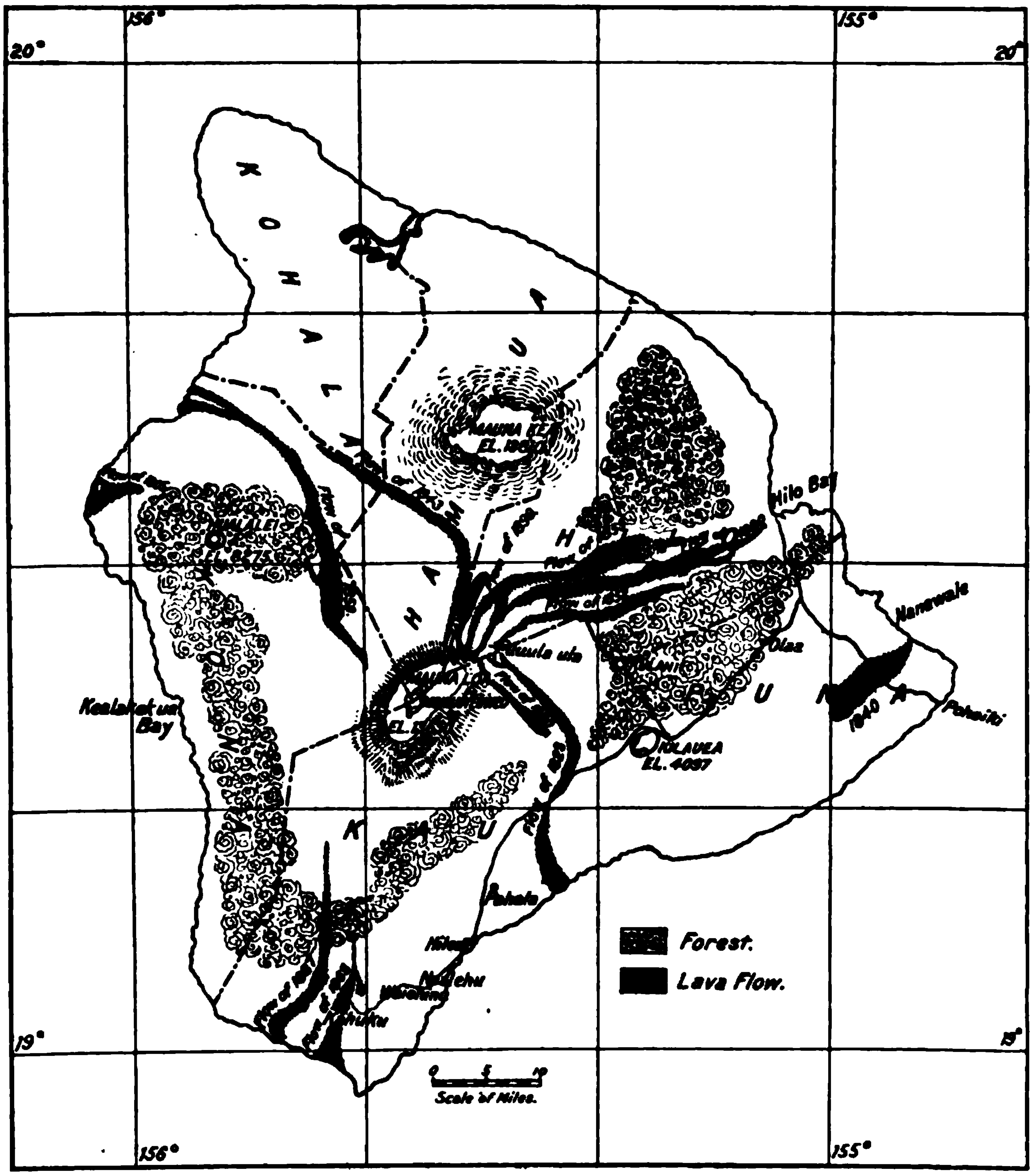


FIGURE 1.—*Map of Hawaii*

and which reticulate on the side of the mountain. The entire mass has been built up by these streams, issuing at irregular intervals from orifices and crevices. It would require millions of years at the known rate of increase for the present century to construct this dome. Though so modern, the surface is unbroken by denudation in its upper portions.

In Olaa and elsewhere near the sea shallow canyons are beginning to show themselves.

Volcanic Ashes

At the New York meeting of the American Association for the Advancement of Science, in 1887,* I represented that what had been called oceanic sediments † in various benches and buttes were really volcanic ashes. I have examined these deposits more carefully during the past year, and substantiate the earlier position.

The annexed outline map ‡ is constructed so as to show the areas occupied by these ashes so far as known. It is needful first to describe the location of the forest. In Hamakua, Hilo, and Puna districts it flanks Mauna Kea and Mauna Loa from about 300 to 7,000 feet altitude. Interrupted for 10 miles by Kilauea, it commences again near Ainapo, runs down to Kahuka, and curves to the north, extending through Kona. Its presence is due primarily to the rainfall, which is excessive (175 to 200 inches) in the more eastern section. Sugar plantations are located below the forest, on the windward slopes, and the planters have discovered that when the ground has been cleared of trees the land is well fitted for the growth of the cane and coffee. In Olaa there seems to be a connection between the fertility and the prevalence of the ashes. Formerly the Volcano road from Hilo avoided the forest, except for about three miles, near the lower end, because of the mud. Since the recent opening of the region to settlement a new macadamized road has been constructed through a dozen miles of the forest, and this portion of the woodland is underlaid by the ashes. Away from the trees the ashes have been covered up, and the hard basalt has not disintegrated sufficiently to form a soil. On much of this fertile land a slender twig can be easily thrust down for six feet, so loose is the material.

The area below the forest land in Puna is very extensive, and this for much of the district is due to the absence of friable material, not to aridity. It is here that the lava flowed to the sea at Nanawale from Kilauea in 1840. Taking a road recently constructed from the ninth milepost out of Hilo on the Volcano road to Pohoiki (Rycrofts), I discovered the reason for the partly fertile and partly sterile tracts. Near the coast there is a dense growth of the Pandanus or screw pine. Higher up there is much guava and various shrubs. The flow of 1840 is still conspicuous by the sparse vegetation upon it, and sufficient time has not elapsed

* Proc. Amer. Assoc. Adv. Sci., vol. xxxvi.

† Fourth Annual Report of the U. S. Geol. Survey.

‡ Figure 1 is copied from Alexander's published map, drawn by W. A. Wall, 1886.

since the adjacent older streams appeared to allow much loose earth to accumulate on them. I found two small areas of an ancient discharge which were not covered by the later basalts, and retained the original dense forest. One is a mile in diameter, east of Pahoa post-office; the other is much smaller, near the eighteenth mile-post. Large ohias, tree ferns, ropy vines, and various shrubs are as vigorous in these small outliers as in the upper forest, while the interspaces exhibit chiefly "pahoehoe" basalt of recent origin, devoid of vegetation. The natural conclusion is that the forest originally covered all the Puna district, and that the lava flowed down so plentifully from Kilauea or Mauna Loa that most of the region was covered and the trees destroyed. The soil of these two outlying patches and of the 3 miles of forest crossed by the road near Hilo came from the disintegration of basalt.

The soil derived from volcanic ash extends along the Volcano road for 10 miles above Olaa village. Sections at the twenty-first mile-post show two beds, each 6 feet thick, separated by a black band of vegetable humus, with roots, thus indicating two separate discharges, the second appearing many years after the first—a period long enough to allow of the growth of a forest before that too was overwhelmed. Because of the great rainfall these beds have been converted into a red clay. Similar duplex deposits appear at the twenty-second and twenty-third mile-posts. Above the twenty-fifth mile post the forest and ash both disappear and the surface consists of pahoehoe, bare of vegetation. This extends to about a mile east of Kilauea, where the vigorous vegetation still remains. No effort was made to follow this stream of lava to its source, nor to demonstrate its connection with the barren tract outside of the forests extending toward Pahoa. The various facts stated will illustrate the method that may be employed to determine the position and succession of prehistoric lava flows on Hawaii. "Aa" streams of great antiquity underlie the ashes in the Olaa forest, apparently originating from Mauna Loa. Kilauea emitted ashes, stones, and lava bombs at a more recent date. They have been noticed extending a mile east of the volcano, 4 miles southwest from the pit and toward Keauhau. They are coarser than the ash, of greater extent, and of a darker color, and contain pisolite. It is very common to the southwest.

The older ash is first seen about 4 miles southwest of Kilauea, and appears in occasional spots as far as the Halfway house. It then increases in amount and importance. Midway between the Halfway house and Pahala there is a terrace of it 1,800 feet in altitude. In this neighborhood it distinctly underlies both "aa" and pahoehoe. At Pahala it is very thick and dry. The Hawaiians formerly amused themselves by jumping into these piles of dust as though it were a liquid. The

cane fields are considerably higher up than the mill, where water is plentiful.

Numerous bluffs show themselves in the higher slopes, where large blocks have been elevated unequally by dynamic forces. One of these elevations is the famous Hilea " butte " figured by Captain C. E. Dutton. According to him, "the buttes are mere remnants of a large alluvial formation which was originally continuous."* The material is certainly like silt, but the theory of its eolian origin, rained down from an atmosphere charged with volcanic dust, better accommodates itself to all the phenomena than that of marine accumulation. Immense " aa " flows between Hilea and Naalehu destroy the continuity of the deposit, and it underlies the fertile fields of Waiohinu and other tracts as far as to the Kahuka ranch of Colonel Norris. Here the continuity has been interrupted by the flow of 1868. There is an interesting depression in the ash here, a crater-like opening a hundred feet deep and a thousand across, used as a hot-house for the growth of fruits and vegetables.

Mr J. S. Emerson states that this ash is abundant in Kona, and others have observed it by the seashore near the terminus of the 1868 flow. The western edge is abrupt, 10 feet thick. King Umi, who reigned eight or ten centuries ago, built a road through Kona on the surface of this dust; hence we know the time of its eruption reached very far back, probably before the existence of the Hawaiians on the island. The ash is said to be divided in the middle by a white layer.

The region north of Hilo contains this same bed. At the village of Hilo it is exposed in a cutting by the house of Judge D. H. Hitchcock. Several miles to the north it appears in the road adjacent to the shore, and it is highly probable that the long array of sugar plantations in this district is underlaid by the same. In climbing Mauna Kea I found this ash abundant on the south slope, especially at Puakala, more than 6,000 feet above the sea. It was of noticeable thickness.

Origin of the Ashes

As to origin of the ashes, it is evident:

1. That they represent at least two eruptions, separated by an interval of considerable duration.

2. As the beds are alike in number on opposite sides of the island, we should naturally look for their source at Mokuaweoweo, a central point, rather than the neighborhood of Hilea or from Kulani, on the eastern slope.

* Fourth Ann. Rept. U. S. Geol. Survey, p. 98.

3. Kilauea destroyed the continuity of this tuffaceous deposit by intercalating its own discharges of ashes, lava bombs, rubble, and lava.

4. Certainly 2,000 square miles of Hawaii have a generous supply of these ashes. They must have occupied many times this amount of space if we take into account those that fell into the ocean. Having had the opportunity of studying the ashes thrown out by Tarawera, New Zealand, in 1886, I have no hesitation in saying that the Hawaiian deposit far exceeded it in size. There only 82 square miles were covered by a layer exceeding 3 feet in thickness; here it would not be extravagant to say that more than 1,500 square miles were thus covered. The total area covered by the New Zealand deposit amounted to 6,200 square miles.

The eruptions producing the ashes must have been of the explosive type; hence we must believe that volcanoes may represent both the Strombolian and the Vesuvian phases of activity at different periods in their history. Most writers upon the Hawaiian volcanoes have insisted that all their eruptions were of the quiet kind.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 57-92 FEBRUARY 25, 1901

GEOLOGICAL RECORD OF THE ROCKY MOUNTAIN REGION IN CANADA

ADDRESS BY THE PRESIDENT, GEORGE M. DAWSON

(Read before the Society December 29, 1900)

CONTENTS

INTRODUCTION

It is the privilege of the President of this Society, in his address, to bring to the notice of his fellow-members some subject possessed of more or less general interest, and preferably, I think, some subject that he has made particularly his own. On such an occasion a wider outlook upon various geological fields becomes admissible than in the case of papers presented to the Society, which, as a rule, should be devoted to original and unpublished observations. It has thus appeared to me that it may be of interest and utility at this time, to collect and review the main facts so far ascertained respecting the composition of the geological column of what may be called the Rocky Mountain region of Canada, including the province of British Columbia and the Yukon district—this region

being identical with that part of the western Cordillera comprised in the Dominion of Canada. To its geological exploration a great part of my own time has been devoted for many years. The results, as obtained, have been published chiefly in the reports of the Geological Survey of Canada, but it is undoubtedly difficult for the inquirer, with only a limited amount of time at his disposal, to form a connected and balanced idea of the conditions, as a whole, from a series of such progress reports, dealing usually with particular districts.

Twenty years ago, after having worked in British Columbia or on its borders for six seasons, I read a paper before the Geological Section of the British Association for the Advancement of Science, at Swansea, entitled "Sketch of the geology of British Columbia," which was afterwards published in the Geological Magazine.* So far as they go, the general outlines then laid down still hold; but much has been accomplished since that time, the relative importance of the observations recorded has been considerably changed, and opinions expressed from time to time have had to be modified as the work progressed. All I shall attempt to do here is to review the principal geological features as they are now understood, but in order to render this address of more practical value as a clue to the geology of the region covered by its title, references to the principal reports and papers in which details may be found will be given throughout.

Special Features of the Region

The region dealt with is in many respects one of particular geological interest, and it is likewise remarkable as one which it has been necessary to work out as an almost entirely detached geological problem. Its older rocks are separated from those of the eastern parts of Canada by the whole width of the Great plains, and the newer formations found in it are generally unrepresented in other parts of Canada. Nor until the work was well advanced did any satisfactory standard of comparison exist in the far west. California could be referred to in regard to certain defined formations of the Tertiary and Cretaceous, but a great intervening region of the Cordillera remained practically unknown geologically, except for the earlier results of the Hayden surveys and some reconnaissance surveys by other explorers along lines of travel. Clarence King's great volume, the "Systematic Geology of the 40th Parallel," did not appear till 1878, and the relations of the region here referred to with others, which have become apparent, have been developed at later dates.

* Decade II, vol. viii, April and May, 1881.

It was in this region also that the occurrence of contemporaneous volcanic materials as important constituents of the Mesozoic and Paleozoic rocks of the Cordilleran belt was first recognized. Previous to the earlier reports of the Canadian Geological Survey on British Columbia, the existence of such volcanic materials had been admitted only as regards the Tertiary formations, in the western portion of the continent.

Investigators

The geological exploration of British Columbia was begun in 1871 by Dr A. R. C. Selwyn, assisted by the late Mr James Richardson. Taking all the circumstances into consideration, the report then made by Dr Selwyn must, I think, be regarded as a remarkably valuable and important one. My own investigations in connection with the Geological Survey began in 1875 and in 1887 extended to the Yukon district. Work was carried on in the Cariboo district for some years under the control of the late Mr Amos Bowman, and in later years Messrs J. McEvoy, R. G. McConnell, J. B. Tyrrell, R. W. Brock, and J. C. Gwillim have also been in charge of parties in different parts of this Cordilleran region of Canada.

Physiographical Features

It is not my intention, however, here to follow the development of our knowledge of the region historically, through its various stages, but rather to enumerate the several formations now known to be represented, to briefly describe each of them, and then to review the main outlines of the geological evolution of this part of the continent in so far as it has been made apparent. For this purpose a few words must first be devoted to the existing physiographical features of the region.

Pleistocene events and matters connected with the glaciation and later superficial geology may be excluded from consideration, as these have been treated at some length elsewhere.*

As compared with the Cordilleran region in the Western states, that of British Columbia is much less diffuse and more strictly parallel with the corresponding part of the Pacific coast. Its length is approximately the same, but its width is usually about 400 miles only. The several mountain systems are separated by narrower intervals, and, except in the extreme north, may be more readily traced and defined. All the main physical features trend in a north-northwest direction for about 1,100 miles, after which the mountain axes turn somewhat abruptly westward,

* Trans. Royal Soc. Can., vol. viii. Presidential address to Section IV.

and, becoming less continuous and separated by wider intervening lowlands, run toward the eastern boundary of Alaska.

The geological features follow a similar rule, the rock series represented differing much in age and composition within comparatively short distances as the Cordilleran belt is crossed, while they run far and with closely accordant characters in the direction of its length.

This depends on two conditions, both imposed by the position of the zone of recurrent crustal movements coincident with the western border of the continent: (1) The occurrence of successive zones of deposition, whether sedimentary or volcanic, parallel to the continental edge; (2) the actual compression of the original area of deposition, by folding and fracture, produced by pressure from the Pacific side, by means of which the superficies may have been reduced by at least one-third of its original width since early Paleozoic times. It results, further, from these conditions that the local names applied to geological formations remain appropriate for long distances in the general direction of the strike, while the characters associated with such names can seldom be traced far without change in a transverse direction. The bearing of this on the nomenclature appropriate for the Cordilleran region as a whole is important, and the want of attention to it has already, I fear, led to the publication of some new formational names which are unnecessary and confusing rather than helpful.

The ruling orographic features of the Cordilleran region in Canada at the present time are the Rocky mountains proper, forming its high eastern border, and the Coast ranges of British Columbia on the west. It has been proposed by Dana to name the first of these systems the "Laramide range," as its origin was coeval with the close of the Laramie period. This mountain system appears to begin about the 46th or 47th parallel of latitude, from which it runs in a northerly direction to the Arctic ocean, with occasional echelon-like breaks, but forming throughout the western limit of the inland plain of the continent. Its width is about 60 miles, and although reduced in the far north, the height of many of its peaks exceeds 11,000 feet. The rocks composing it are for the most part referable to the Paleozoic, and it is found to be affected by numerous great faults parallel to its direction, overthrust to the eastward, and along the eastern margin, resulting in some cases in horizontal displacements of several miles, by which Paleozoic rocks override those of Cretaceous age in the foothills.

The Coast ranges of British Columbia form a belt of about 100 miles in width that extends along the border of the Pacific for at least 900 miles, beginning near the estuary of the Fraser and eventually running inland beyond the head of Lynn canal, where the coast changes its trend

to the westward. These ranges are chiefly composed of granitic rocks, which may in the main be regarded as forming a gigantic " bathylite " with minor included masses of sedimentary rocks. It is later in date of origin than the Triassic period and probably experienced a second and much greater elevation at or about the close of the Cretaceous, but is neither so lofty nor so ragged as the Laramide range. The remarkable fiords of the Pacific coast, both those of British Columbia and those of the southern part of Alaska, are the submerged valleys of this coastal system of mountains, their erosion being probably referable to early Eocene and late Pliocene times, during which the land stood at relatively high levels.

To the west of the Laramide range, and separated from it by a remarkably long and direct structural valley, is a somewhat irregular and sometimes interrupted series of mountain systems to which the general name of the Gold ranges has been applied, and this is referred to further on as the Archean axis of this part of the Cordillera. It embraces the Purcell, Selkirk, Columbia and Cariboo mountains, all including very ancient rocks and evidently representing the oldest known axis of elevation in the province, although it has not remained unaffected by movements of much later date. Peaks surpassing 10,000 feet in elevation still occur in these mountains.

Between the Gold and Coast ranges, with a width of about 100 miles, is the Interior plateau of British Columbia, a peneplain referred in its main features to the early Tertiary, which has subsequently been greatly modified by volcanic accumulations of the Miocene, and has been dissected by river erosion at a still later period. This plateau country is well defined for a length of about 500 miles, declining northward from a height of over 4,000 feet near the 49th parallel to one of less than 3,000 feet, and with an average altitude of about 3,500 feet. It is then interrupted for some four degrees of latitude by a mountainous country chiefly composed of disturbed Cretaceous rocks, beyond which the surface again declines to the plateau lands of the upper Yukon basin, with its separated mountain ranges. The Interior plateau is throughout very complex in its geological structure, but except where covered by Tertiary accumulations it is found to be chiefly underlain by Paleozoic and Mesozoic rocks.

One more mountain system remains to be noted. This stands upon the real border of the Continental plateau, and is represented by the long ridge-like highlands of Vancouver island and the Queen Charlotte islands. It is evidently broken between these islands, and is not clearly continued in the archipelago of southern Alaska, which seems to be more closely connected with the Coast ranges of the mainland. The

rocks principally comprised in this outer mountain system range from the Carboniferous to the Cretaceous in age.

TABLE OF GEOLOGICAL FORMATIONS

Attention may now be directed to the general table of geological formations recognized in the region under review. This is arranged in two main columns, representing what I conceive to be the two great geosynclines of this part of the Cordillera. These are separated by what has already been referred to as an Archean axis. A further explanation of these main structural features will be given subsequently, but it is first proposed to define and briefly note the character of each of the geological units, beginning with the oldest.

	Western Geosyncline	Feet		Laramide Geosyncline	Feet
Pliocene	Horsefly gravels. Quartz drift of Klondike, etc.				
Miocene	Upper volcanic group	3,100			
	Tranquille beds	1,000			
	Lower volcanic group	5,300			
Oligocene	Coldwater group (Similkameen beds, etc.).	5,000			
Eocene	Puget group (on coast only 3,000′ +).			Upper Laramie	3,000
				Lower Laramie	2,500
Cretaceous	Nanaimo group	2,700		Montana } Colorado }	3,140
	Queen Charlotte Island group (in Queen Charlotte islands).	9,500		Dakota } Kootanie }	9,750
Triassic	Nicola group	13,500		(Red beds to south, marine to north) say	600
Carboniferous	Cache Creek group	9,500		Banff series	5,100
Devonian	(?)			Intermediate series	1,500
Silurian	(?)			Halysites beds	1,300
Ordovician	(?)			Graptolithic shales	1,500
				Castle Mountain group (upper part). }	8,000
Cambrian	Adams Lake series	25,000	Selkirk series, 25,000	Castle Mountain group (lower part). }	
	Nisconlith	15,000		Bow River series	10,000
		89,600			46,390
Archean	Shuswap series 5,000′ +				

ARCHEAN

In 1881 it was possible only to allude to the existence of crystalline rocks probably referable to the Archean. The rocks referred to were those originally described by Dr Selwyn as the "Granite, gneiss, and

mica-schist of the North Thompson, etc.," and recognized from the first by him as "the oldest rocks observed in the country." It was not, however, till 1889 that much further information was gained regarding these old rocks, when good sections of them were found by the writer on Kootenay lake, and as they were also well developed on Shuswap lake, the name Shuswap series was proposed for them.* The Shuswap rocks proper evidently represent highly metamorphosed sediments with perhaps the addition of contemporaneous bedded volcanic materials. They are grayish mica-gneisses, with some garnetiferous and hornblendic gneisses, glittering mica-schists, crystalline limestones and quartzites. Gneisses in association with the last-mentioned rocks often become highly calcareous or silicious and contain scales of graphite, which are also often present in the limestones. These bedded materials are, however, associated with a much greater volume of mica-schists and gneisses of more massive appearance, most of which are evidently foliated plutonic rocks, and are often found to pass into unfoliated granites. The association of these different classes of rocks is so close that it may never be possible to separate them on the map over any considerable area. The granites may often have been truly eruptive in origin, but the frequent recurrence of quartzites among them in some regions indicates that they are, at least in part, the result of a further alteration of the bedded rocks.†

Thus, up to the present time, the Shuswap series has been made to include this entire complex mass of crystalline rocks, although it might be more appropriately restricted to the originally bedded members. These, it will be observed, now very closely resemble those of the Grenville series of the province of Quebec, the resemblance extending to the nature of their association with the foliated rocks, which in turn closely resemble the so-called "Fundamental Gneiss" of the same region. The original materials and the conditions of alteration to which they have been subjected have in both localities been almost identical, producing like results. The age must be approximately the same, but the distance is too great to admit of any precise correlation on lithological grounds.

When the ruling lines of strike or foliation of the Shuswap are laid down, they are generally found to be parallel with each other in each particular region, but to run in great irregular sweeping curves over the face of the map as a whole, and sometimes to surround unfoliated granitic areas in a concentric manner, the whole appearance being very much like that met with in some parts of the Laurentian country in the east.

*Annual Report, Geol. Surv. Can., vol. iv (N. S.), p. 29 B. The name Kootanie (or Kootenay) was preoccupied.

† Cf. Shuswap map-sheet, Geol. Surv. Can., 1898.

A distinct tendency to parallelism of the strata or foliation with adjacent borders of the Cambrian system has moreover also been noted in a number of cases. This might imply that the foliation was largely produced at a time later than the Cambrian, but the materials of some of the Cambrian rocks show that the Shuswap series must have fully assumed their crystalline character before the Cambrian period, and there are other evidences of their extensive pre-Cambrian erosion. It seems, therefore, probable that the foliation of the Shuswap rocks may have been produced rather beneath the mere weight of superincumbent strata than by pressure of a tangential character accompanied by folding, and that both these rocks and those of the Cambrian were at a later date folded together. In the Archean of eastern Canada, foliation still nearly horizontal or inclined at low angles, often characterizes considerable areas and appears to call for some explanation similar to that above suggested.

The greatest thickness of the Shuswap rocks so far measured, where there is no suspicion of repetition, on Kootenay lake, is about 5,000 feet, but even here there are doubtles included considerable intercalations of foliated eruptives. The Shuswap series characterizes considerable areas of the Selkirk, Columbia, and adjacent ranges in the southern part of British Columbia. It is known also in the Cariboo mountains and near the sources of the North Thompson and Fraser, about latitude 53°.* It is again well developed on the Finlay river, where the country has been geologically examined, between the 56th and 57th parallels of latitude.†

Northward to this point these rocks appear to be confined to a belt lying to the west of the Laramide range and to come to the surface seldom, if at all, in that range. Farther north similar rocks occur in the Yukon district in several ranges lying more to the west, but still with nearly identical characters, in so far as they are known. ‡

The granitic rocks of the Coast ranges are probably much newer, nor have any crystalline schists yet been observed in association with these raeges to which an Archean date can be definitely assigned.

Cambrian

The importance of rocks assigned to the Cambrian in the Rocky Mountain region of Canada has become much more apparent as the result of later explorations. Their thickness is very great, and they appear under differing characters in different parts of the region, in

* Annual Report, Geol. Surv. Can., vol. xi (N. S.), p. 39 D.

† Ibid., vol. vii, p. 33 C.

‡ Ibid., vol. iii, p. 34 B, and vol. iv, p. 14 D.

such a manner as to require distinctive names and to admit, so far, of only a tentative correlation. Our typical and most carefully surveyed section is that in the Rocky mountains proper or Laramide range, on the line of the Bow River pass. This has been studied by Mr R. G. McConnell, and it is the only section for which some direct paleontological evidence exists.* The base of the Cambrian is, however, not seen in this section. In the Gold ranges, where the Cambrian is frequently found resting on the Archean, the Nisconlith, its lowest recognized member, varies by several thousand feet in volume, showing that the old surface was a very irregular one and had been greatly modified by denudation previous to the deposition of the Nisconlith. The same circumstance has been noticed by Mr McConnell in the case of the Bow River series of the Laramide range, where it is found resting on the Archean in the vicinity of the Finlay river, over 400 miles northwest of his typical section,† proving this denudation-interval to be a very important one, although, as already noted, there is often a parallelism in strike between the two series of rocks.

The Bow River series, in the pass of the same name, consists chiefly of dark-gray argillites, with some greenish and purplish bands, associated with quartzites and conglomerates, these coarser materials being most abundant in the upper parts of the formation. Pebbles of quartz and feldspar, evidently derived from the Archean, are abundant in the conglomerates, and scales of mica have in some places been developed on the divisional planes of the argillites. The known thickness of the series is 10,000 feet.

In the eastern part of the pass, resting conformably on the Bow River series, is the Castle Mountain group, with a known thickness of about 8,000 feet. This consists chiefly of ordinary gray limestones and dolomites, in frequent alternations and interstratified with shales and calc-schists. To the west of the main watershed, however, the character of this series becomes materially changed, and the heavy bedded dolomites and limestones are to a great extent replaced by greenish calc-schists and greenish and reddish shales and slates. The change may be traced in its various stages, and is due to the introduction on the west of a greater proportion of earthy matter.

Fossils of the lower Cambrian (*Olenellus*) fauna have been found 3,000 feet below the summit of the Bow River series. They are also known to characterize the lower part of the Castle Mountain series, which is fos-

* For details of the Bow River Pass section, see Annual Report, Geol. Surv. Can., vol. ii (N. S.), part D.

† Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 24 C.

siliferous at several horizons, and appears to pass up at its summit into the Ordovician.*

Following the general direction of the Laramide range northwestward, Cambrian rocks similar to those of the Bow pass are now known at intervals for many hundred miles, and it is probable that they will be found to form a continuous or nearly continuous belt. Both groups are recognized with practically identical characters on the Yellow Head pass and on the Finlay river. The Misinchinca schists of my report of 1879, no doubt represent the Bow River series, and similar rocks are again found at the sources of the Pelly branch of the Yukon.†

Passing now to the next mountain system, to the southwest of the Laramide range and parallel with it—the Gold ranges—we find in the Selkirk mountains a great thickness of rocks that have not yet yielded any fossils, but appear to represent, more or less exactly, the Cambrian of our typical section. Resting on the Archean rocks of the Shuswap series is an estimated volume of 15,000 feet of dark gray or blackish argillite schists or phyllites, usually calcareous, and toward the base with one or more beds of nearly pure limestone and a considerable thickness of gray flaggy quartzites. To these, where first defined in the vicinity of the Shuswap lakes, the name Nisconlith series has been applied.‡ The rocks vary a good deal in different areas, and on Great Shuswap lake are often locally represented by a considerable thickness of blackish flaggy limestone. It other portions of their extent dark-gray quartzites or graywackes are notably abundant. Their color is almost everywhere due to carbonaceous matter, probably often graphitic, and the abundance of carbon in them must be regarded as a somewhat notable and characteristic feature. These beds have also been recognized in the southern part of the West Kootenay district and in the western portion of the Interior plateau of British Columbia.

The Nisconlith series is believed, from its stratigraphical position and because of its lithological similarity, to represent in a general way the Bow River series of the adjacent and parallel Laramide range, but there is reason to think that its upper limit is somewhat below that assigned on lithological grounds to the Bow River series.

Conformably overlying the Nisconlith in the Selkirk mountains, and blending with it at the junction to some extent, is the Selkirk series,

* For descriptions of the fossils from these beds, the following authors may be referred to: C. Rominger, Proc. Acad. Nat. Sci., Phila., 1887, pp. 12-19; C. D. Walcott, Proc. U. S. Nat. Mus., 1889. pp. 441-446; J. F. Whiteaves, Can. Rec. Sci., 1892, vol. v, pp. 205-208; F. R. C. Reed, Geol. Mag., 1899, Dec. 4, vol. vi, pp. 358-361; G. F. Matthews. Trans. Royal Soc. Can., series 2, vol. v, sec. 4.

† Annual Report Geol. Surv. Can., vol. xi (N. S.), p. 31 D. Ibid., vol. vii, p. 34 C. Report of Progress, Geol. Suvr. Can., 1879-'80, p. 108 B.

‡ Annual Report Geol. Surv. Can., vol. iv (N. S.), p. 31 B. Bull. Geol. Soc. Am., vol. ii, p. 170. Annual Report Geol. Surv. Can., vol. vii (N. S.), p. 31 B. Shuswap map-sheet, Geol. Surv. Can.

with an estimated thickness of 25,000 feet, consisting, where not rendered micaceous by pressure, of gray and greenish-gray schists and quartzites, sometimes with conglomerates and occasional intercalations of blackish argillites like those of the Nisconlith. These rocks are evidently in the main equivalent to the Castle Mountain group, representing that group as affected by the further and nearly complete substitution of clastic materials for the limestones of its eastern development.

In the vicinity of Shuswap lakes and on the western border of the Interior plateau, the beds overlying the Nisconlith and there occupying the place of the Selkirk series are found to still further change their character. These rocks have been named the Adams Lake series.* They consist chiefly of green and gray chloritic, felspathic, sericitic, and sometimes nacreous schists, greenish colors preponderating in the lower and gray in the upper parts of the section. Silicious conglomerates are but rarely seen, and on following the series beyond the flexures of the mountain region it is found to be represented by volcanic agglomerates and ash-beds, with diabases and other effusive rocks, into which the passage may be traced by easy gradations.† The best sections are found where these materials have been almost completely foliated and much altered by dynamic metamorphism, but the approximate thickness of this series is again about 25,000 feet.‡

The upper part of the Cambrian system, above the Bow River and Nisconlith series, may thus be said to be represented chiefly by limestones in the eastern part of the Laramide range, calc-schists in the western part of the same range, quartzites, graywackes, and conglomerates in the Selkirk mountains, and by volcanic materials still further to the west. It is believed that a gradual passage exists from one to another of these zones, and that the finer ashy materials of volcanic origin have extended in appreciable quantity eastward to what is now the continental watershed in the Laramide range. No contemporaneous volcanic materials have, however, been observed in the underlying Bow River or Nisconlith series.

The beds first definitely referred to the Cambrian in the Rocky Mountain region of Canada are those found near the International boundary in the vicinity of the South Kootenay pass.§ These were further examined at a later date, as described in the report of the Geological Survey of Canada for 1885,|| and some additional observations in regard to them are given by Mr J. McEvoy.¶

---

* For the Selkirk and Adams Lake series see references above given for Nisconlith series.

† Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 35 B.

‡ Comprising greenish schists 8,100 feet, grayish schists 17,100 feet. In Bull. Geol. Soc. Am., vol. ii, p. 166, the thickness is given in error at half the above.

§ Geology and Resources of the 49th Parallel, p. 68. Geol. Mag., Decade II, vol. iii, p. 222.

|| Pp. 39 B–42 B.

¶ Summary Report, Geol. Surv. Can., 1899, p. 97 A.

A thickness of at least 11,000 feet of sandstones and shales of red, gray, and greenish colors, frequently alternating and including several contemporaneous trap flows, occurs between the Continental watershed and the Flathead river. This series has not been traced into connection with the sections previously described, but it shows some resemblance to the Selkirk and Castle Mountain groups. The occurrence of blackish calcareous argillites and sandstones at the base may indicate the presence of the Bow River series there, while a limestone at the top of the section in this part of the mountains may prove to be that of the Castle Mountain group.*

Along the eastern borders of the Coast ranges, in southern British Columbia, is a very considerable volume of argillites with some limestone and altered volcanic products, all more or less schistose or slaty. These were originally described by Selwyn as the "Anderson River and Boston Bar group." † They may be Cambrian, but it has not yet been found possible to separate them from newer Paleozoic rocks with which they are associated.

Additional Cambrian areas will no doubt also eventually be defined in the far north, including some of the rocks met with on the Stikine and Dease rivers and in the Klondike district.‡

Ordovician and Silurian

As already noted, the upper part of the Castle Mountain group in the Laramide range contains fossils referable to the Ordovician. In the same western part of the range, 1,500 feet or less of black shales lies above these, containing graptolites that have been referred to the Trenton-Utica fauna by Professor Lapworth.§ The same graptolitic fauna was found in 1887 on the Dease river, not far south of the 60th parallel of latitude.‖

Above the graptolitic beds in the Bow Pass section, is a thickness of 1,300 feet or more of dolomites and quartzites, containing *Halysites catenulatus* and a few other forms that are believed to be Silurian.¶

The above-mentioned localities are the only ones in which Ordovician or Silurian rocks have been discovered in the entire region under review.

Devonian

East of the continental watershed, on the Bow pass, Mr McConnell's

* Annual Report, Geol. Surv. Can., vol. i (N. S.), pp. 50 B, 51 B.
† Ibid., vol. vii, pp. 38 B, 43 B.
‡ Ibid., vol. iii (N. S.), pp. 32 B, 94 B. Summary Report, Geol. Surv. Can., 1899, p. 18 A.
§ Annual Report, Geol. Surv. Can., vol. ii, (N. S.), p. 22 D.
‖ Ibid., vol. iii, p. 95 B.
¶ Ibid., vol. ii, p. 21 D.

section shows a thickness of 1,500 feet of brownish-weathering dolomitic limestones, named by him the Intermediate limestones, that from their fauna and position are described as Devonian.* They pass conformably upward into beds of the Banff series, which are regarded as Carboniferous in the main, although, as so commonly occurs in the Rocky mountain region, they appear to contain also a certain number of forms usually referred to the Devonian.

A few fossils supposed to be distinctively Devonian, have likewise been found in several other isolated localities in this Laramide range, and as the Devonian system is well characterized and persistent along the Mackenzie river, as well as in the Manitoba region, it seems probable that a continuous zone of the same age may ultimately be traced throughout the eastern parts at least of the Laramide range. To the west of this range no distinct evidence of rocks of Devonian age has, however, been obtained, although it is quite probable that such rocks may yet be found as constituents of the lower part of the Cache Creek formation described below.†

CARBONIFEROUS

In describing the rocks of this period, it will be convenient first to refer to those of the Bow pass, continuing the general east-to-west order previously followed, but premising that this is not the order in which the respective rock-series have actually been studied or named.

The mountains of the eastern part of the Laramide range, in the vicinity of the Bow pass, are largely formed of the Banff Limestone series, having a thickness of about 5,100 feet. This is composed of two thicknesses of limestone, separated by one shaly zone, and the whole capped by a second zone of shales. The aggregate thickness of the shales is about 1,300 feet. Below the Banff series, in this part of the mountains, is the Intermediate limestone, already noted, and above it is the Earlier Cretaceous, resting upon it without any apparent unconformity.‡ Numerous fossils have been obtained from the limestones, showing their position to be in the lower part of the Carboniferous system, passing below into Devono-Carboniferous.§ Limestones of the Banff series have now been recognized in many localities scattered along almost the entire length of

* Ibid., vol. ii, p. 19 D.

† The entire field of the Devonian in Canada has lately been reviewed by Dr J. F. Whiteaves (see Presidential address, Section E, Am. Assoc. Adv. Sci., 1899).

‡ Annual Report, Geol. Surv. Can., vol. ii (N. S.), p. 17 D.

§ The existence of Carboniferous and Devonian fossils in this range was first made known many years ago by Dr (now Sir James) Hector. Exploration of British North America, p. 239, Quart Jour. Geol. Soc., vol. vii, p. 443.

the Laramide range in Canada, in which direction the conditions of d(osition appear to have been uniform.

Rocks of the Carboniferous period are probably present in seve parts of the system of Gold ranges, but practically no paleontologi evidence of their existence has yet been obtained.*

Between these mountains and the Coast ranges, however, the Carb(iferous is again well represented, but in a manner very different from tl found in the Laramide range, for although limestones are still importa clastic rocks of various kinds, with great masses of contemporane(volcanic materials, preponderate. These rocks occupy a considera part of the Interior plateau of southern British Columbia, and run nor westward, with practically identical characters, far into the Yukon (trict, probably to the eastern boundary of Alaska and beyond.

Fossils referable to the Carboniferous period are found sparingly association with them, particularly *Fusulinæ*, and none of distinctiv older or more recent date have been discovered. At the same time, i not improbable that the series may include in its lower part beds ol than the Carboniferous, and possible that its upper beds may be ne than those of that system. Its constant characters, however, rende appropriate to attach a distinctive name to the series, which has coı quently been designated the Cache Creek series, with the understand that should any part of it subsequently be discovered to be separa paleontologically, the name will be retained for the Carboniferous port This name is, in fact, somewhat more important than a purely local (being intended to denote a peculiar development of the Carbonifer system, well defined in its nature and characterizing a wide middle z in the northern part of the Cordilleran belt, but of which the upper lower limits still remain somewhat indefinite.

The name is one of those of Selwyn's preliminary classification, wl Lower and Upper Cache Creek groups are described, the term " Ma Canyon limestones" being given as an alternative for the latter. division into lower and upper parts on lithological grounds is still ognized, but later investigations and the proved Carboniferous ag both parts have since caused the whole to be referred to as a single g group.†

The composition and approximate thickness of the Cache Creek st are best known in the area of the Kamloops map-sheet, where it be briefly characterized as follows: The lower division consists of a lites, generally as slates or schists, cherty quartzites or hornstones,

* Summary Reports, Geol. Surv. Can., 1895, p. 24 A; 1896, p. 22 A; 1897, p. 29 A.

† See Report of Progress, Geol. Surv. Can., 1871-'72, pp. 52, 60, 61; also Annual Report, Surv. Can., vol. vii (N. S.), p. 32 B et seq.

canic materials with serpentine and interstratified limestones. The volcanic materials are most abundant in the upper part of this division, largely constituting it. The minimum volume of the strata of this division is about 6,500 feet. The upper division, or Marble Canyon limestones, consists almost entirely of massive limestones, but with occasional intercalations of rocks similar to those characterizing the lower part. Its volume is about 3,000 feet.

The total thickness of the group in this region would therefore be about 9,500 feet, and this is regarded as a minimum. The argillites are generally dark, often black, and the so-called cherty quartzites are probably often silicified argillites. The volcanic members are usually much decomposed diabases or diabase-porphyrites, both effusive and fragmental, and have frequently been rendered more or less schistose by pressure. The serpentine beds are associated with these volcanic rocks, and have evidently resulted from the alteration of some of them. The limestones of both lower and upper divisions hold *Fusulina* and a few other distinctive Carboniferous fossils, but in the Marble Canyon limestone the most characteristic form is the large foraminifer known as *Loftusia columbiana*, entire beds being made up of its débris.†

Fusuline limestones have now been found in a number of places in the central zone of the Cordillera throughout the length of British Columbia and beyond the 60th parallel, its northern boundary. Where these occur the clastic and volcanic rocks associated with them may be definitely referred to the Cache Creek group, but in consequence of the great resemblance of its volcanic rocks to those of the Triassic (as mentioned later), it is often impossible, without close study, to define the area occupied by this group, and its separate mapping has only as yet been attempted in detail over comparatively small areas.‡

In the southern part of British Columbia, the Cache Creek group shows some evidences of littoral conditions toward the west slopes of the Gold ranges, probably indicating the existence of land areas there. In this vicinity also the Campbell Creek beds, a somewhat peculiar development of argillites, graywackes, and amphibolites, occur.§

The granitic Coast ranges of British Columbia are much later in date of origin than the Carboniferous, but some of the highly altered beds now included in them or found along their margins are undoubtedly of that period. To the west of these ranges, on Vancouver island and in

* Ibid., p. 46 B.

† Quart. Jour. Geol. Soc., vol. xxxv, p. 69.

‡ Areas included in the Kamloops and Shuswap map-sheets, covering together 12,800 square miles.

§ Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 44 B.

its vicinity, as well as on the Queen Charlotte islands, are rocks very similar in composition to those of the Cache Creek of the interior, but still differing somewhat from these in aspect. They comprise limestones and volcanic accumulations preponderantly, with occasional zones of argillite. The limestones are usually in the form of marbles, often coarsely crystalline, but from them a few fossils referred to the Carboniferous period have been obtained. The volcanic materials include amygdaloids, agglomerates, and tuffs, but are often converted to schists, and sometimes become mica-schists or imperfect gneisses, as in the vicinity of Victoria. Their degree of alteration is very different locally, and their aspect consequently varies much from place to place, but on the whole they evidence conditions of deposition much like those of the Cache Creek group.* They have unfortunately not yet been made the subject of any detailed study, and they are again involved with Triassic strata closely resembling them in aspect.

Triassic

In my report for 1877 † the existence in British Columbia of rocks shown by their fossils to be referable to the Triassic was made known, and these rocks, as developed in the Interior plateau region, were named the Nicola series or formation. This rests, at least in some places, unconformably upon the Carboniferous, and no rocks representing the Permean period have been identified. The Nicola formation is, however, chiefly composed of volcanic materials, the intercalated limestones or argillites in which fossils are occasionally found being few and far between. The greater part of its mass is undoubtedly Triassic, but the highest beds in a few places have yielded a small fauna that is referred by Professor Hyatt to the Lower Jurassic. All the fossils are marine.‡

Partial sections of the Nicola formation have been obtained in a number of places, but its study is attended with difficulty, owing to the very massive and uniform character of the most of its rocks, the region covered by it being best characterized as one of "greenstones." These rocks often closely resemble those of the Carboniferous, and in some places it is not easy to separate them, on the other hand, from the older Tertiary volcanic materials. Lithologically the rocks are chiefly altered diabases of green, gray, blackish, and purplish colors. In regard to state of aggregation, they comprise effusives (often amygdaloidal), agglomerates, and tuffs, the latter showing evidence of subaqueous deposition through-

* Geol. Mag., Decade II, vol. viii, p. 219.

† Report of Progress, Geol. Surv. Can., 1877-'78.

‡ Fossils of the Triassic rocks of British Columbia, J. F. Whiteaves, Contributions to Canadian Paleontology, vol. i, part 2. Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 49 B et seq.

out the entire series. The tuffs are occasionally calcareous, and there are some thin and probably irregular beds of limestone, with infrequent layers of argillite. The most complete section so far obtained is one on the Thompson river, showing a total thickness of 13,590 feet; another near Nicola lake gives a probable minimum of 7,500 feet, and in both places more than nine-tenths of the whole is of volcanic origin.

The Nicola formation, with the characteristics above noted, is well developed in the central parts of the Interior plateau of British Columbia, and it probably extends far to the north in the same belt of country between the Coast and Gold ranges, but in the general absence of paleontological evidence, can not there as yet be separated, even locally, from the Paleozoic.*

To the west of the Coast ranges, and now entirely separated from the Nicola formation by the granitic mass of these ranges of later age, Triassic rocks are again found largely developed in the Queen Charlotte islands and on Vancouver island. They were described and identified in the Queen Charlotte islands in 1878, and in 1885, when again found covering large areas in the northern part of Vancouver island, were defined as the Vancouver series.†

These rocks closely resemble those of the Nicola formation, with which they may probably at the time of their deposition have been continuous. The series is built up for the most part of volcanic materials, now in the state of altered diabases and felsites, but amygdaloidal, agglomeratic, or tuffaceous in character. Ordinary sedimentary materials, such as argillites, limestones, and felsites, are, however, more abundant than in the Nicola formation. These probably recur at several different horizons, but in the northern part of Vancouver island they are known to form an important zone, with a thickness of about 2,500 feet.‡ Marine fossils are abundant in some of these beds.

This group is of great thickness, but no trustworthy figures can yet be given for it. It is associated often with the very similar rocks of the Carboniferous period, already referred to as existing in the same orographic belt, and it yet remains to draw a distinct line between the two series. Following the coastal region northward, rocks pretty clearly referable to this formation have been noted in several places among the Alaskan islands as far up as Lynn canal.

To the north of the 56th degree of latitude, it would appear that the

* Annual Report, Geol. Surv. Can., vol. iii (N. S.), p. 33 B.

† Report of Progress, Geol. Surv. Can., 1878–'79, p. 49 B. Annual Report, Geol. Surv. Can., vol. ii (N. S.), p. 7 B et seq. The rocks named the Sooke series, in 1876, may probably also be included in the Vancouver series. Report of Progress, Geol. Surv. Can., 1876–'77, pp. 98–102.

‡ The same zone is probably represented in the southern part of the Queen Charlotte islands.

Triassic sea extended eastward, without important interruption, across the entire Cordilleran region, as marine fossils like those of the Vancouver group have been found not only on the Stikine (in the trend of the Nicola formation), but also on the Liard, Peace, and Pine rivers in the Laramide range.* In the last-named range, however, there is no evidence of contemporaneous volcanic action, which. it is probable, did not extend so far to the eastward.

Following the Laramide range southward from the occurrences last alluded to, there is a considerable interval in which no Triassic rocks have been recognized, after which, in the vicinity of the 49th parallel, a series of red sandstones and shales, with buff magnesian grits, three or four hundred feet thick, is found. This caps a number of the higher mountain ridges and was assigned by me in 1875 to the Triassic. It is believed to represent the northern extremity of the deposits of the Triassic Mediterranean that occupied so large a part of the Western states and which must have been separated from the open sea by land barriers of some width.†

Cretaceous

Apart from the beds capping the Nicola formation, to which allusion has been made, no strata distinctly referable to the Jurassic have been found in the Rocky Mountain region of Canada. Wherever their relations have been determined, the Cretaceous rocks lie unconformably on the Nicola and Vancouver formations, and it seems probable that this unconformity represents the greater part of the Jurassic period. It is proper, however, to state that the lower measures here included in the Cretaceous are still by some authorities called Jurassic; but it is believed that the paleontological evidence, when compared with the best recognized general standards (and not merely with local isolated developments to which a Jurassic age happens to have been assigned), is overwhelmingly in favor of the Cretaceous reference.‡

There is in the region here treated of an important Earlier Cretaceous series of rocks, mostly of marine origin, the distribution of which shows

* Annual Report, Geol. Surv. Can., vol. iii (N. S.), p. 54 B. Ibid., vol. iv, p. 19 D. Report of Progress, Geol. Surv. Can., 1875–'76, p. 97. Bull. Geol. Soc. Am., vol. v, p. 122.

† Geology and Resources of 49th Parallel, 1875, p. 71. Trans. Royal Soc. Can., vol. i, sec. iv, p. 143 et seq.

‡ Cf. Whiteaves: Mesozoic Fossils, vol. i, part iv, 1900.

In a late article in the Journal of Geology (Chicago), vol. viii, pp. 245–258, Mr W. N. Logan groups the Jurassic beds found at the summit of the Nicola group (*not* at Nicola lake) with parts of the Queen Charlotte and Kootanie formations, here described as Earlier Cretaceous, and which we have found no reason to separate from the rest of that series, calling the whole Jurassic By so doing he gives a large part of the area of the Earlier Cretaceous sea to the Jurassic, in a manner which I believe to be incorrect (cf. Am. Jour. Sci., vol. xxxviii, p. 121).

that (except in the southern part of British Columbia), the Pacific at this time, as in the later Triassic, extended to the eastward quite across the Cordilleran belt. In different parts of the region these rocks have been included under two names—the Queen Charlotte Islands and Kootanie formations. The former, applied at first particularly to the Earlier Cretaceous of the coast, has been extended to cover that of the whole western part and interior of the Cordillera. The latter is used to denote the Earlier Cretaceous of the Laramide range and its vicinity, which differs considerably in character.*

In the Queen Charlotte islands we have the clearest succession of beds and the largest and best studied representation of marine organic remains. The entire Cretaceous section as known on these islands is as follows, in descending order: †

(A) *Upper shales and sandstones*......................	1,500 feet.
(B) *Coarse conglomerates*.............................	2,000 "
(C) Lower shales and sandstones (with coal)........	5,000 "
(D) Agglomerates....................................	3,500 "
(E) Lower sandstones..............................	1,000 "
	13,000 feet.

It is the three lower members of this section that are regarded as composing the Queen Charlotte Islands formation. Subdivision C contains the greater number of fossils, eighty-nine species of invertebrates having now been described from it,‡ and most of the forms found in subdivision E are identical with these. The intervening agglomerates, of volcanic origin, may be local, and in any case probably represent but a comparatively short space of time. The overlying subdivisions, A and B, are believed to be Upper Cretaceous and approximately equivalent to the Niobrara, Benton, and Dakota of the interior portions of North America.

In the southern part of British Columbia, east of the Coast ranges (which are at least in great part of subsequent origin), the Earlier Cretaceous rocks of the Queen Charlotte islands are represented in the Tatlayoco beds (7,000 feet), Nechacco beds (6,000 feet), Skeena beds, Skagit beds (4,400 feet or more), and Jackass Mountain beds (5,000 feet). These inland terranes of the southwestern part of British Columbia are clearly comparable with the "Shasta group" of California and Oregon, and the fauna most abundantly represented in them is that of the Knox-

* The facts in regard to these rocks are somewhat fully summarized in Am. Jour. Sci., vol. xxxviii, p. 120 et seq., and in Annual Report, Geol. Surv. Can., vol. vii (N. S.), 1894, p. 62 B et seq., where numerous references to the literature may be found.

† Report of Progress, Geol. Surv. Can., 1878-'79, p. 63 B.

‡ Mesozoic Fossils, vol. i, part iv (1900), p. 305.

ville or lower division now made of that group, the characteristic *Aucella* of which is often the commonest fossil.* In the northern part of the province, between the 55th and 58th parallels of latitude, rocks chiefly referable to this period have lately been found to characterize a wide area of country east of the Coast ranges, and here, as well as in the south, they frequently hold coal.

On Tatlayoco lake, the beds of the same name are found to be underlain in apparent conformity by rocks of volcanic origin, to which the name "Porphyrite series" was originally applied.† No fossils have been found in these, but the similarly constituted Iltasyouco beds (latitude 53°) contain molluscs that are now referred by Dr Whiteaves to the Queen Charlotte formation.‡ Ash beds containing similar fossils have been discovered on the Skeena to the east of the Coast ranges, and it is thus evident that vulcanism played an important part in this Earlier Cretaceous time, not only in the Queen Charlotte islands, but also further to the eastward.

Fossils representing the same Earlier Cretaceous period have been found in late years far to the north, in the Yukon basin, on the Lewes river, and on the Porcupine, beyond the Arctic circle.§

The Kootanie formation was so named and characterized as Lower Cretaceous, because of its peculiar flora, by Sir J. Wm. Dawson in 1885.‖ It represents the Earlier Cretaceous of the Laramide region in Canadian territory, and has since been found to extend a considerable distance into Montana. Its typical area is separated from the Cretaceous of the western part of British Columbia by the Selkirk and other ranges that appear to have existed as dry land at this time. It no doubt blends with the Queen Charlotte formation further to the north, and it may eventually be found that no useful line can be maintained between the two formations. The Kootanie seems, however, to have been for the most part deposited in a fresh or brackish water basin, and for some years scarcely any marine forms were known to occur in it.¶ A number of

* Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 64 B.

† Geol. Mag., Decade II, vol. iv, July, 1877.

‡ Originally described as Jurassic. See Geol. Mag., Decade II, vol. viii, p. 218, and Dr Whiteaves on the "Cretaceous system in Canada," Trans. Roy. Soc. Can., vol. xi, sec. iv (1893). For descriptions of invertebrate fossils of the Cretaceous, see especially the following works by Dr J. F. Whiteaves: Mesozoic Fossils, vol. i, parts 1, 2, 3, and 4; Contributions to Canadian Paleontology, vol. i, part 2; Trans. Roy. Soc. Can., vol. i, sec. iv, p. 81; ibid. (second series), vol. i, pp. 101, 119.

§ Annual Report, Geol. Surv. Can., vol. iii (N. S.), p. 36 B. Ibid., vol. ix, pp. 21 D, 124 D. et seq.

‖ Science, vol. v, p. 531. Trans. Roy. Soc. Can., vol. iii, sec. iv. For descriptions of Cretaceous plants see particularly the following papers by Sir J. Wm. Dawson, in Trans. Roy. Soc. Can.: Cretaceous and Tertiary Floras of British Columbia, vol. i (1882); Mesozoic Floras of the Rocky Mountain Region, vol. iii (1895); Correlation of Early Cretaceous Floras, etc., vol. x (1892); New Cretaceous plants from Vancouver Island, vol. xi (1893).

¶ Annual Report, Geol. Surv. Can., vol. i (N. S.), p. 162 B.

marine molluscs have, however, since been found at the base of the formation, in the Devils Lake deposits, not far north of the Bow river, and these Dr Whiteaves has provisionally referred to the age of the fossiliferous beds of Queen Charlotte islands, thus apparently confirming the general correlation already indicated by the fossil plants.

The Kootanie consists of alternating sandstones and shales with some thin bands of limestone toward the base and holding in parts of its extent numerous and thick seams of bituminous and anthracite coal, the latter occurring where it has been closely included in the mountain folding. Its thickness is about 7,000 feet, including only that part of the general section characterized by its fossils. Above this is a thickness of 4,000 or 5,000 feet, largely made up of conglomerates that are supposed to represent the Dakota group.

Conglomerates occupying about the same stratigraphical position in the Queen Charlotte islands have already been alluded to, and similar important conglomerates attached to or closely associated with the Earlier Cretaceous have been found in many places on the mainland of British Columbia and northward to the Yukon district. These conglomerates appear throughout to be approximately contemporaneous and are believed to be of more than local significance. They evidently mark a time of wide subsidence and of shorelines advancing on the land, and it was at this time that the Cretaceous Dakota sea spread itself eastward across the interior plain of the continent.

In the Fraser valley east of the Coast ranges, in addition to the occurrence of the conglomerates, the existence of beds of about the period of the Dakota is shown by the discovery of a few fossil plants;* but no evidence of higher members of the Cretaceous has been found in the inland region to the west of the Selkirks, although it is probable that such members are represented further north, in the Yukon district.

From a systematic point of view, it appears to be desirable to confine the Earlier Cretaceous, or Queen Charlotte formation, to rocks below the Dakota; but it will be understood that, over a considerable part of the inland country, the earlier rocks are intimately associated with those of about Dakota age, and that where those of still later date are not present, the most natural break, and one coinciding with some notable physical change, would be above the Dakota.

Beds referred to the Upper Cretaceous† in the Queen Charlotte Islands section have already been alluded to. Collectively it is supposed that the two upper members of that section represent the Dakota, Benton,

*Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 148 B.

† For references in regard to the Upper Cretaceous see Geol. Mag., Decade II, vol. viii, p. 216; also Am. Jour. Sci., vol. xxxix (1890), p. 180 et seq.

and Niobrara. In following the coast southeastward from the Queen Charlotte islands, the local base of the Cretaceous rocks is found at progressively higher horizons in that system. The two lowest members of the Queen Charlotte section are wanting in the northern part of Vancouver island, and farther on, in the Comox and Nanaimo coal fields, the base of the measures is approximately equivalent to the highest part of the Queen Charlotte Islands section.

The Cretaceous section at Comox has been divided on lithological grounds into seven, that at Nanaimo into three, members by Mr J. Richardson. While unnecessary to refer to these in detail here, it may be stated that they correspond pretty closely, and that the well marked and abundant fauna and flora of the Upper Cretaceous of the coast of British Columbia characterizes the four lower subdivisions at Nanaimo and the two lower subdivisions at Comox, the thickness of the strata being estimated at 2,715 and 2,020 feet respectively. These subdivisions have been united under the name of the Nanaimo group,* and this is believed to be almost exactly equivalent to the Chico of California and at least approximately to the Pierre of the Great plains. At both Nanaimo and Comox the workable coal seams occur in the lowest subdivision of this group.

As already noted, beds referable to the Upper or later Cretaceous are known to occur in the far north. The fossils indicate a horizon at least as high as that of the Benton, and it is very probable that further investigation may disclose the existence of a complete ascending series, like that found in the Laramide range and its adjacent foothills to the east.

In the Laramide range, the Upper Cretaceous includes representatives of all the Cretaceous groups of the Great plains, but generally with more massive developments and altered characters, resulting from proximity to an extensive land surface to the westward, from which abundant and often coarse sediments were derived. This is particularly notable in the case of the Dakota, to which allusion has already been made in connection with the Kootanie. It may here be added that contemporaneous volcanic materials, with a thickness of over 2,000 feet in one locality, have been found in this group in the eastern part of the Crows Nest pass.†

The aggregate thickness of the Upper Cretaceous in the southern part of the Laramide range (including the lower portion of the Laramie, which may be regarded as Cretaceous) is found to be about 10,000 feet.‡ It is unnecessary, however, to do more than allude to this section here, as it is

---

* Am. Jour. Sci., loc. cit.

† Annual Report, Geol. Surv. Can., vol. I (N. S.), p. 69 B.

‡ Ibid., p. 166 B.

more properly to be regarded as the western margin of the Cretaceous of the plains than as characteristic of the Cordilleran region. Its characters have been, moreover, quite adequately summarized elsewhere, particularly by Dr Whiteaves in his paper previously referred to.

The Laramie is regarded as a series transitional between the Cretaceous and Tertiary, and in the Laramide range and its foothills passes up from a brackish-water to a purely fresh-water deposit. No beds probably referable to this time have been found between this range and the Pacific coast in the entire southern part of British Columbia, but in the extreme north of that province, some deposits apparently referable to the Upper Laramie occur,* while it is also present in considerable volume in parts of the Yukon district.†

On the Pacific coast, the Puget group of Washington has been referred with probability to the period represented by the Laramie, and rocks of this group have a somewhat extensive development about the estuary of the Fraser, with a thickness of at least 3,000 feet. They appear to have been deposited in fresh or brackish water, and hold some beds of lignite.‡ The upper subdivisions of the Nanaimo and Comox sections, from which no distinctive organic remains have yet been obtained, may also prove to represent the Puget group, or the marine Tejon of California, which is perhaps no lower.

Tertiary

It has been convenient to refer to the Laramie as a whole in connection with the Cretaceous, although the Upper Laramie is regarded as Eocene. The Puget beds of the Fraser estuary and Burrard inlet, just alluded to, have always been described as Tertiary, and were for a long time regarded as Miocene.

Subsequent to the Cretaceous period and the great orogenic movements that accompanied its close, the physical conditions in the Rocky Mountain region of Canada became much more like those existing today. The Eocene appears for the most part to have been a time of denudation,§ but later Tertiary deposits occur in many places and often in extensive development. On the coast these are usually marine, but no marine beds have been found to the east of the Coast ranges, although it seems possible that evidence may yet be found in the north of the extension of the sea at this time as far east as the upper Canadian portion of the Yukon basin.

* Ibid., vol. vii, p. 35 C.

† Ibid., vol. iii, p. 149 B.

‡ Am. Jour. Sci., vol. xxxiv, p. 182. For descriptions of plants see Trans. Royal Soc. Can., second series, vol. i, sec. iv (1895), p. 135.

§ Trans. Royal Soc. Can., vol. viii, sec. iv, p. 11.

The Tertiary sediments of the interior are chiefly those of lake basins, large or small, but the great mass of the Tertiary rocks is composed of volcanic materials, a circumstance accounting for the general paucity of organic remains, which, together with the isolated positions of the known fossiliferous localities, renders it very difficult to build up a satisfactory and connected section of the Tertiary formations.*

Some progress has, however, been made in this respect, particularly in the southern part of the Interior plateau of British Columbia, where the following scheme, which may be taken as a term of reference for the whole inland region, has been arrived at.† The order is descending:

	Feet
Later Miocene. Upper Volcanic group (maximum thickness)	3,100
Tranquille beds (maximum thickness)	1,000
Earlier Miocene. Lower Volcanic group (maximum thickness apart from centers of eruption)	5,300
Oligocene. Coldwater group (at Hat creek)	5,000
	14,400

Beginning with the oldest member of the above section, it may be explained that more or less isolated series of beds in different parts of the Interior plateau region have lately been classed together provisionally as the Coldwater group. These resemble each other lithologically, and all appear to antedate the beginning of Tertiary volcanic action in this part of the region. One of their developments, from which the greatest number of fossils has been derived, has frequently been referred to in earlier publications as the "Similkameen beds," but the name Coldwater group is preferred as a general one, including these as a local development. From the Similkameen beds, plants, insects, and a few fish remains have been obtained. These have been described by Sir J. Wm. Dawson, Dr S. H. Scudder, and Professor E. D. Cope, who agree in referring them with probability to the Oligocene. The fish is an *Amyzon*, like that from the Amyzon beds of Oregon.‡ Much farther north, on the Horsefly river, a tributary of the Quesnel, well preserved remains of another fish of the same genus have been found, and again in association with similar plant remains. Elsewhere plants only, or a few insects, have been discovered.

The deposits of the Coldwater group consist of conglomerates, shales, and sandstones which not infrequently hold beds of lignite or, as at the

* For earlier references to the Tertiary deposits of the region, see Geol. Mag., Decade II, vol. viii, foot-notes to pp. 158, 162.

† Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 76 B. Detailed descriptions of the several groups in the southern part of British Columbia are also given in this report.

‡ Tertiary plants of the Similkameen river; Trans. Royal Soc. Can., vol. viii, sec. iv (1890), p. 75. Contributions to Can. Pal., vol. ii, part i. Proc. Acad. Nat. Sci. Phil., vol. xlv (1893), p. 401.

junction of the Coldwater and Nicola rivers, bituminous coal. At the base the conglomerates are often rough and coarse, composed of the local underlying rocks, upon which they rest irregularly, but above these, in several places in the southern part of the Interior plateau, are thick beds of well rolled and generally small pebbles derived for the most part from the cherty beds of the Cache Creek formation. The sandstones and shales are usually pale-colored, gray, buff, or drab, except where they become carbonaceous.*

Speaking of the southern part of British Columbia, where the Tertiary deposits have been examined with some care, it appears that the beds of the Coldwater group were, at least locally, disturbed and subjected to considerable erosion before the deposition of the overlying materials assigned to the Miocene. These are almost entirely of volcanic origin, and over a considerable area they admit of separation into lower and upper volcanic groups, between which are the water-laid Tranquille beds.

The principal volcanic vents of the early Miocene appear to have been situated near to and parallel with the inland border of the Coast ranges, their denuded remnants being now found in the Clear mountains, Ilgachuz mountain, etcetera. Both effusive and fragmental rocks are represented in the products of this period, which, petrographically considered, consist chiefly of augite-porphyrites, of gray, greenish, and purplish colors, with smaller amounts of mica-porphyrites, picrite-porphyrites, etc. These generally form massive beds, and are now found inclined in many places at angles as high as 30 degrees from the horizontal, although to what extent this may represent the natural slope of deposition and in how far it may be due to subsequent movement is often indeterminate.

The Tranquille beds consist generally of bedded tuffs, and are usually pale in color. They occasionally contain plant remains and some thin beds of coal or lignite, as at Kamloops.† The upper volcanic group is composed for the most part of basalts and basalt-breccias, with smaller quantities of various porphyrites, mica-trachyte, and mica-andesite. The basalts often occur in horizontal flows of great extent, their eruption having marked the closing stage of the great Tertiary period of vulcanism. Their sources may have been numerous and local, and they are often

* The Kenai formation of Dall, found in some parts of Alaska, is believed by Dall to be either Oligocene or Eocene. The statement, however, that the Kenai is also "widely spread in British Columbia" is too comprehensive. It may be supposed to refer to formations like that here described, widely separated geographically and differing in conditions of deposition from the typical Kenai of Cooks inlet. In such a case the elevation of a local formational name into a regional chronological term is in no way helpful and should, I think, be deprecated. (See Bull. No. 84, U. S. Geol. Survey, Annual Report, U. S. Geol. Survey, 1895–'96, part i, p. 481. Ibid., 1896–'97, part ii, p. 345.)

† Annual Report, Geol. Surv. Can. (N. S.), vol. vii, p. 169 B.

found forming a comparatively thin sheet that lies directly on the denuded surface of the older rocks without the intervention of any of the earlier members of the Tertiary. As these wide basaltic flows are in most cases known to antedate the great period of river erosion assigned to the Pliocene, they are supposed to be of later Miocene age. It is, of course, possible that local eruptions of more recent date may have occurred, but only one instance of a comparatively recent or postglacial lava flow has so far been found in the entire Cordilleran region of Canada. This is in the valley of the Nasse river.*

In the northern interior of British Columbia, lake deposits have been found, in some places, blending above with volcanic materials and capped by horizontal basalts, the whole being very probably referable to the Miocene. In other places, both in British Columbia and in the Yukon district, local flows of basalt are found which may belong either to the Miocene or to the Pliocene. The same is true of isolated basalt patches in the Kettle River country in the southen part of British Columbia and in East Kootenay. On the Nechacco river and elsewhere, Tertiary shales or clays, with sandstones, of indeterminate horizon are also found. It will be many years before all these deposits can be investigated and classified, and it may never be possible to assign an exact position to some of them in the general series. The great paucity, amounting almost to a complete absence, of the remains of the higher vertebrates being particularly unfortunate in this respect.

In the southern part of the Interior plateau of British Columbia, small areas have been found of sediments that are supposed to belong to the early Pliocene,† but no fossils have been obtained from them. On the Horsefly river, however, overlying the Oligocene beds already referred to in slight but distinct unconformity, and underlying the boulder-clay, is a deposit of yellowish and in part "cemented" gravels, to which a Pliocene age may be assigned with some confidence.‡ These gravels are worked for gold, and branches and stems of trees found in the workings have been determined by Professor D. P. Penhallow to represent *Sequoia gigantia*, *S. sempervirens*, *Juniperus californica*, *Cupressus macrocarpa*, *Thuya gigantia*, and *Picea sitchensis*.§

The presence of such an assemblage of trees in the inland region north of latitude 52°, indicates the existence of physical and climatic conditions very different from those now existing there and still more unlike those of the intervening glacial period, while the species themselves are still living ones.

* Summary Report, Geol. Surv. Can., 1893, p. 14 A.
† Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 74 B.
‡ Ibid., p. 26 A.
§ These determinations have not previously been published.

Similar yellow gravels have been found on the Upper Fraser and on its tributary, the Blackwater, in several places, and it is probable that they are somewhat widespread in this district.* It is very possible that they are at least approximately synchronous with the old auriferous preglacial stream gravels of the Cariboo mountains, and are also of the same age with the "yellow gravels" of the Atlin district.

The Tertiary deposits of the Coast region of British Columbia are wholly separated from those of the interior by the physical barrier of the Coast ranges. They are interesting, but not of great extent, occurring in isolated patches and not forming, as they do farther to the south, a nearly continuous border to the continent. The sedimentary beds are for the most part of marine origin, and are still found near the level of the sea, little disturbed or altered.

Sandstones holding marine shells occur at Sooke, on the southern coast of Vancouver island. These beds were first described by Mr J. Richardson.† Mr J. C. Merriam has since studied the fossils, and they appear to be referable to the Upper Miocene or Pliocene ("Middle Neocene").‡ Farther west, on the same coast, are the Carmanah beds, consisting of sandstones, shales, and conglomerates. These are referred by the same author to the "Astoria Miocene" § or Astoria group, and are recognized as older than the Sooke beds. A remarkable bird, *Cyphornis magnus*, had previously been described by Cope from the Carmanah beds, and this he states is not older than Eocene nor later than Oligocene.|| Plant remains also occur, but they have not so far been studied. Elsewhere on the west coast of Vancouver island and farther north small patches of Tertiary rocks are found, which have not yet been examined, and from which no fossils have been obtained.

The most important development of Tertiary rocks on the coast is that forming the northeastern part of Graham island, the northern member of the Queen Charlotte group. The considerable tract of land underlain by these rocks is relatively low, and most of the prominent rock masses consist of basalt with some volcanic materials of a less basic character, and in one place obsidian, fragmental as well as effusive rocks being represented. In a few places, underlying sandstones and shales come to the surface, sometimes holding lignite, and at one locality marine shells are abundantly represented. These have been examined by

* Annual Report, Geol. Surv. Can., vol. vii (N. S.), p. 28 A; also Report of Progress, Geol. Surv. Can., 1875–'76, pp. 263, 264.

† Report of Progress, Geol. Surv. Can., 1876–'77, p. 190.

‡ Bull. Univ. Cal., Geology, vol. ii, no. 3, p. 101; Proc. Cal. Acad. Sci., third series, vol. i, no. 6, p. 175.

§ Op. cit.

|| Jour. Acad. Nat. Sci. Phila., vol. ix, p. 449. The bird is described from a single bone. The exact locality is not given in the paper, not being known to Cope at the time.

Dr. Whiteaves. They include a number of still living forms, but may be regarded as Pliocene or later Miocene.*

Physical History of the Region

It will now be endeavored to briefly review the orographic changes and the conditions of deposition of which the geological column gives evidence—in other words, to touch in outline the main facts of the physical history of the Rocky Mountain region of Canada.

As for the Archean, it need only be said that here, as in most parts of the world, we find beneath any rocks that can be assigned to the Cambrian in the most extended sense of that term, and apparently separated from these rocks by a great break and unconformity, a crystalline series or "fundamental complex" composed of plutonic rocks with highly metamorphosed and vanishing sedimentary rocks in seemingly inextricable association. The similarity of this basal series in different parts of the world is so great as apparently to imply world-wide and approximately contemporaneous conditions, of a kind perhaps differing from any that can have occurred at later periods. The region here described is not, however, an ideal one for the study of these Archean rocks, because of the extreme metamorphism by which much newer formations have often been affected in it; nor has any series yet been defined that appears here to bridge the gap between the Archean and the strata that may with propriety be attached to the Cambrian.

In the earlier series of deposits assigned to the Cambrian, we discover evidence of a more or less continuous land area occupying the position of the Gold ranges and their northern representatives and aligned in a general northwesterly direction. The Archean rocks were here undergoing denudation, and it is along this axis that they are still chiefly exposed, for although they may at more than one time have been entirely buried beneath accumulating strata, they have been brought to the surface again by succeeding uplifts and renewed denudation. We find here, in effect, an Archean axis or geanticline that constitutes, I believe, the key to the structure of this entire region of the Cordillera. To the east of it lies the Laramide geosyncline (with the conception of which Dana has familiarized us), on the west another and wider geosyncline, to which more detailed allusion will be made later.

Conglomerates in the Bow River series indicate sea margins on the east side of this old land, but these are not a marked feature in the Nisconlith, or corresponding series on its western side. Fossils have so far been discovered only in the upper part of the Bow River series, but the preva-

*See Report of Progress, Geol. Surv. Can., 1878-'79, p. 87 B.

lence of carbonaceous and calcareous material (particularly in the Nisconlith) appears to indicate the abundant presence of organisms of some kind at this time.

Although no evidence has been found of any great physical break, the conditions indicated by the upper half of the Cambrian are very different from those of the lower. Volcanic materials, due to local eruptions, were accumulated in great mass in the region bordering on the Archean axis to the west, while on the east materials of this kind appear to be mingled with the preponderant shore deposits of that side of the Archean land, and to enter sparingly into the composition of the generally calcareous sediments lying still farther eastward. Where these sediments now appear in the eastern part of the Laramide range they are chiefly limestone, indicating marine deposition at a considerable distance from any land.

The history of the Ordovician, Silurian, and Devonian times is very imperfectly known. Marine conditions still prevailed to the eastward of the Archean axis and were probably continuous there, but our knowledge of the region to the west, while as yet almost entirely negative in its character, is not sufficiently complete to enable us to assume the existence of any extensive land area in that quarter. In the Devonian the sea is known to have covered a great area in the interior of the continent, extending far to the north in the Mackenzie basin, and it appears probable that considerable portions of the western part of the Cordilleran region were also submerged, particularly to the north.

About the beginning of the Carboniferous period and thence onward the evidence becomes much more satisfactory and complete. In the earlier part of the Carboniferous, marine sediments, chiefly limestones, were laid down everywhere to the east of the Archean axis, while to the west of that axis (which was probably in large part itself submerged) ordinary clastic deposits, mingled with contemporaneous volcanic materials, were formed, tranquil epochs being marked by the intercalation of occasional limestone beds. It is not clearly apparent from what land the clastic materials were derived, but the area of vulcanism at this time was very great, covering the entire western part of British Columbia to the edge of the continental plateau and, as now known, extending northwestward into Alaska and southward to California.

In the later time of the Carboniferous, however, the volcanic forces declined in their activity, and a great thickness of calcareous marine deposits occurred with little interruption of any kind. The area of land to the eastward was probably increased, for there is some evidence to show a first gentle uprising in the Laramide region at this time (or at least a cessation of subsidence), and no late Carboniferous strata have so far been found there.

No separate record for the Permian has yet been found in this part of the continent, but it must be remembered that, in view of the scanty character of the paleontological evidence, strict taxonomic boundaries can seldom be drawn. At about this time, however, very important changes occurred, for in the Triassic a great part of what is now the inland plain of the continent is found to have become the bed of a sea shut off from the main ocean, in which red rocks with salt and gypsum in some places were laid down. The northern part of this sea appears to have extended into the Canadian region for a short distance, covering the southern portion of the Laramide area. Farther north must have been the land boundary of this sea, and beyond this an extension of the Pacific ocean which swept entirely across the Cordillera. In the southern part of British Columbia, however, this ocean found its shore against the Gold ranges of the Archean axis, where the preceding Carboniferous beds had already been upturned and subjected to denudation. The Laramide region was not affected by volcanic action at this time, but vulcanism on a great scale was resumed in the entire western part of the Cordillera that had previously been similarly affected in the Carboniferous, and the ordinary marine sediments there form intercalations only in a great mass of volcanic products, probably in large part the result of submarine eruptions.

Such definite indications as exist of the Jurassic must, as already noted, be considered as physically attached to the Triassic of the Interior plateau of British Columbia. It is probable that the greater part of the Jurassic period was characterized by renewed orogenic movements and by denudation, for when we are next able to form a connected idea of the physical conditions of the region these are found to have been profoundly modified.

It is to about this time that the elevation of the Sierra Nevada and some other mountain systems in the western states is attributed. In the region here particularly described, the Triassic and older rocks of the Vancouver range, or that forming Vancouver and the Queen Charlotte islands, were upturned, while a similar movement affected the zone now occupied by the British Columbian Coast ranges. These may not have been elevated into a continuous mountain system and barrier to the sea, but in any case the ranges then formed were, before the beginning of the Cretaceous period, largely broken down by denudation, so that the underlying granitic rocks supplied abundant arkose material to some of the lowest Cretaceous beds.

It is also probable that subsidence marked the close of the Jurassic, for in southern British Columbia the Pacific of the Earlier Cretaceous extended more or less continuously across the line of the Coast ranges.

finding its shore not far to the east of this line. Farther north, although not without insular interruptions, it spread over the entire width of the Cordilleran belt, repeating the conditions found in the Triassic, but with the difference that it extended far to the south along the axis of the Laramide geosyncline, in which rapid subsidence had been renewed. In this early Cretaceous sea and along its margins and lagoons the massive fossiliferous rocks of the Queen Charlotte islands and Kootanie formations were accumulated and coal beds were produced. Volcanic activity was renewed in some places, particularly near the present seaward margin of British Columbia. Sedimentation evidently proceeded more rapidly than subsidence in many localities and coal-producing forests, largely composed of cycadaceous plants took possession of the newly formed lands from time to time.

The era of the later Cretaceous appears, however, eventually to have been introduced by a marked general subsidence, which, as already noted, carried the Dakota sea entirely across the inland plain of the continent. The distribution and character of the ensuing Cretaceous formations show that the whole southern part of what is now the mainland of British Columbia soon after became and remained a land area, while the sea was more gradually excluded from the northern part of the Cordillera and continued to occupy the area of the Great plains and the present position of the Laramide range. Along the margin of the continental plateau, however, a renewed subsidence was in the main progressing southward and resulted ultimately in carrying the later Cretaceous sediments into the region of Puget sound.

The closing event of this cycle was the deposition of the Laramie beds on the east and in some places to the north, with probably the Puget group and its representatives on the coast, and this was followed by the most important and widespread orogenic movement of which we find evidence in the entire Rocky Mountain region. At this time the great Laramide range, or Rocky Mountain range proper, was produced, rising on the eastern side of the Archean axis along a zone that had previously been characterized from the dawn of the Paleozoic by almost uninterrupted subsidence and sedimentation. That the pressure causing this upthrust of the Laramide range was from the westward is clearly shown by the great overthrust faults in this range. The stability of the old Archean axis, which it may be supposed had previously sustained the tangential thrust from the Pacific basin, must at this time have been at last overcome. As a part of the result of this, the chief belt of faulted strata in the Laramide range, originally about 50 miles wide, became reduced in width by one-half. How rapidly this great revolution may have occurred we do not know, but it probably occupied no long time

from a geological point of view, and the Laramide range, as first produced, may very possibly have attained a height approaching 20,000 feet.* The thickness of stratified rocks in the geosyncline was at the time probably more than 40,000 feet.

It is difficult to determine to what extent the Archean axis with the Gold ranges and other preexisting mountains were affected at this period of orogenic movement, because of the absence of the newer formations there, but it seems probable that no very important change took place. Farther west, however, the great zone of Coast ranges was elevated, and the corrugated and vertical Cretaceous beds met with even on their inland side, show that large parts of the Interior plateau of British Columbia and of the country in line with it to the northward were flexed and broken. Similar conditions are found to have affected the Cretaceous rocks of Vancouver and the Queen Charlotte islands, of which the mountain axis, previously in existence, was evidently greatly increased in elevation.

The Laramide geosyncline has already been particularly referred to and allusion has been made to the now well recognized fact that by such zones of continued subsidence and deposition the lines of most mountain systems have been determined. To the Laramide geosyncline here, the mountains of the Archean axis—the Gold ranges—stood in much the same relation as the Archean western border of the Wasatch to the Laramide geosyncline in Utah (as described by Dana), but on a larger scale.

On the other or western side of this axis, as already noted, I am now led to regard the zone of country extending to the Vancouver range as a second and wider geosyncline, with a breadth of about 200 miles, in which a thickness of deposits perhaps greater than that of the Laramide, but in the main composed of volcanic ejectamenta, had by this time been accumulated. The volume of the Carboniferous and Triassic rocks alone must have exceeded 20,000 feet. It is probable that to this may be added a great thickness of older rocks,† for the circumstance that volcanic action was so persistent here, and the amount of extravasation resulting from it was so enormous, implies a recognition of the fact that, along this zone (not far from the edge of the continental plateau) the

* This refers particularly to the better known region near the Bow pass. See Annual Report, Geol. Surv. Can. (N. S.), vol. ii, p. 31 D, and Am. Jour. Sci., vol. xlix, p. 463. The base of the mountains may at this time have been nearly at sealevel, or 4,000 feet lower than at present, while the actual height at any time attained would depend upon the rapidity of uplift relatively to denudation. The total height of folded strata is estimated at from 32,000 to 35,000 feet.

† Several thousand feet of Cretaceous rocks must also be added to this thickness near the line of the present Coast ranges, and the total thickness of deposits in the center of this geosyncline must probably have exceeded 40,000 feet.

isogeotherms, with what we may call the plane of granitic fusion, had crept up to a position abnormally near the surface. It is to this probably that we may attribute the apparent absence of Archean rocks in the Coast ranges, or at least the impossibility of defining any rocks of that period there, for these, together no doubt with great volumes of later deposits, may be assumed to have become merged in the rising granitic magma, on which strata of Triassic age are now often found lying directly, arrested in the very process of absorption.*

When the Laramide revolution occurred, by reason of the increasing tangential pressure from the Pacific basin and the growing failure of resistance of the two great geosynclines of this part of the Cordillera, the Laramide range was produced by the folding and fracture of a very thick mass of beds, of which the crystalline base has not yet been revealed by denudation, while in the western trough an eversion of the axis of settlement seems to have occurred, resulting in the appearance of a granitic bathylite of nearly a thousand miles in length, from which the comparatively thin covering of unabsorbed beds was soon afterward almost completely stripped away by ensuing processes of waste.

This last great epoch of mountain making doubtless left the surface of the Cordilleran belt generally with a very strong and newly made relief, which, before the middle of the Tertiary period, is found to have become greatly modified by denudation. Chiefly because no deposits referable to the Eocene or earliest Tertiary have been found in this part of the Cordillera, it is assumed with probability that this was a time of denudation. It is further indicated that it was a time of stability in elevation, by the fact that the prolonged wearing down resulted, in the interior zone of the Cordillera, in the production of a great peneplain, the base-level of which shows that the area affected stood 2,000 or 3,000 feet lower in relation to the sea than it now does, and that for a very long time. If, however, the Puget beds of the coast are correctly referred to the Eocene, it follows that the coast region was at the same period only slightly lower than at present, and that the movements in subsidence and elevation between this and the interior region must have been differential in character and very unequal in amount.

As already noted, the earliest Tertiary sediments of the Interior plateau of the Cordillera are referred to the Oligocene. Probably some further subsidence at that time interrupted the long preceding time of waste. This period of deposition was in turn closed by renewed disturbance of an orogenic kind, comparatively slight in amount and local, chiefly affecting certain lines in a northwest and southeast direction. Next

* Annual Report, Geol. Surv. Can., vol. ii (N. S.), 1886, p. 11 B et seq.

came renewed denudation or "planation," and this continued until the enormous volcanic extravasations of the Miocene began.

It is not proposed in this place to recapitulate in detail the physical conditions of the Tertiary period, for it has already been necessary to refer to these in connection with the description of the beds themselves, which, because they have not been materially changed since their deposition, really tell their own tale.

It need only be said that, after the Oligocene lake deposits had been formed, disturbed, and denuded, new series of lakes were from time to time produced at different stages during the Miocene, their beds now generally appearing as intercalations in volcanic deposits of great mass. Both the coast and the interior region appear to have been subject to these conditions, while the Laramide range stood high, with the inland plain of the continent sloping eastward from its base.

Following the close of, or at least a great reduction in volcanic activity, in the early Pliocene, the interior zone of the Cordillera again assumed a condition of stability for a considerable time, during which wide and "mature" stream valleys were formed. The elevation of the Interior plateau region of British Columbia must then have been about 2,000 feet less than it is at present.* Farther north, the yellow Pliocene gravels of Horsefly river, aud other places, are attributed to this period, and the southern aspect of their contained fossil plants is such as to indicate that, in the given latitude, the height of that part of the interior can not have been much above the sealevel.

In the later Pliocene a very marked reëlevation of the Cordilleran region evidently occurred, leading to the renewed activity of river erosion, the cutting out of deep valleys and canyons, and the shaping of the surface to a form much like that held by it at the present day. This elevation in all probability affected the coast as well as the interior, and it would appear that the rivers for a time extended their courses to the edge of the continental plateau.

The excavation of the remarkable fiords of British Columbia and the southern part of Alaska must, I think, be chiefly attributed to the later portion of the Pliocene, although it is quite possible that the cutting out of the valleys may have been begun soon after the Laramide upheaval. The antiquity of these valleys is evidenced by the fact that several comparatively small rivers still flow completely across the Coast ranges in their deep troughs. The fiords are now essentially the submerged lower parts of these and other drainage valleys of the old land, not very materially affected by the later glacial action, important as this has un-

* Trans. Royal Soc. Can., vol. viii, sec. iv, p. 18.

doubtedly been from other points of view. The valleys of the fiord-like lakes that occur along the flanks of the Archean axis of the interior may probably also be referred to river erosion in the later Pliocene, but if so this mountain region must have been affected by a relatively greater uplift at that time, followed later by a subsidence of its central part. It appears, however, that the excavation of valleys or gorges like these by rivers, when the slope and water supply are favorable, occurs with such rapidity relatively to the wider effects of denudation, as to be almost negligible in any general view of the physical changes of an extensive region or in the accounting of geological time.

There is as yet some difficulty in connecting the later physical changes particularly referred to above with those which have recently come under observation far to the north in the Klondike region. It is probable, however, that the auriferous "quartz drift" of that region, implying long subaerial decay and stability of level, may be attributed to the early Pliocene; while the river gravels found in the newer and deeper-cut valleys may be assigned to the later Pliocene time of greater elevation. During the Pliocene, and probably until its close, the mammoth, one or two species of bison, the moose, and other large mammals roamed northward to the Arctic sea. Then came the Glacial period, with renewed great changes in levels and climate and its own peculiar records and history, which in many respects are more difficult of interpretation than those of more remote periods, because the whole time occupied by them has been relatively so brief. I have elsewhere endeavored to follow this history in detail, and do not propose on this occasion to deal with this latest chapter of the physical history of the Rocky Mountain region of Canada.

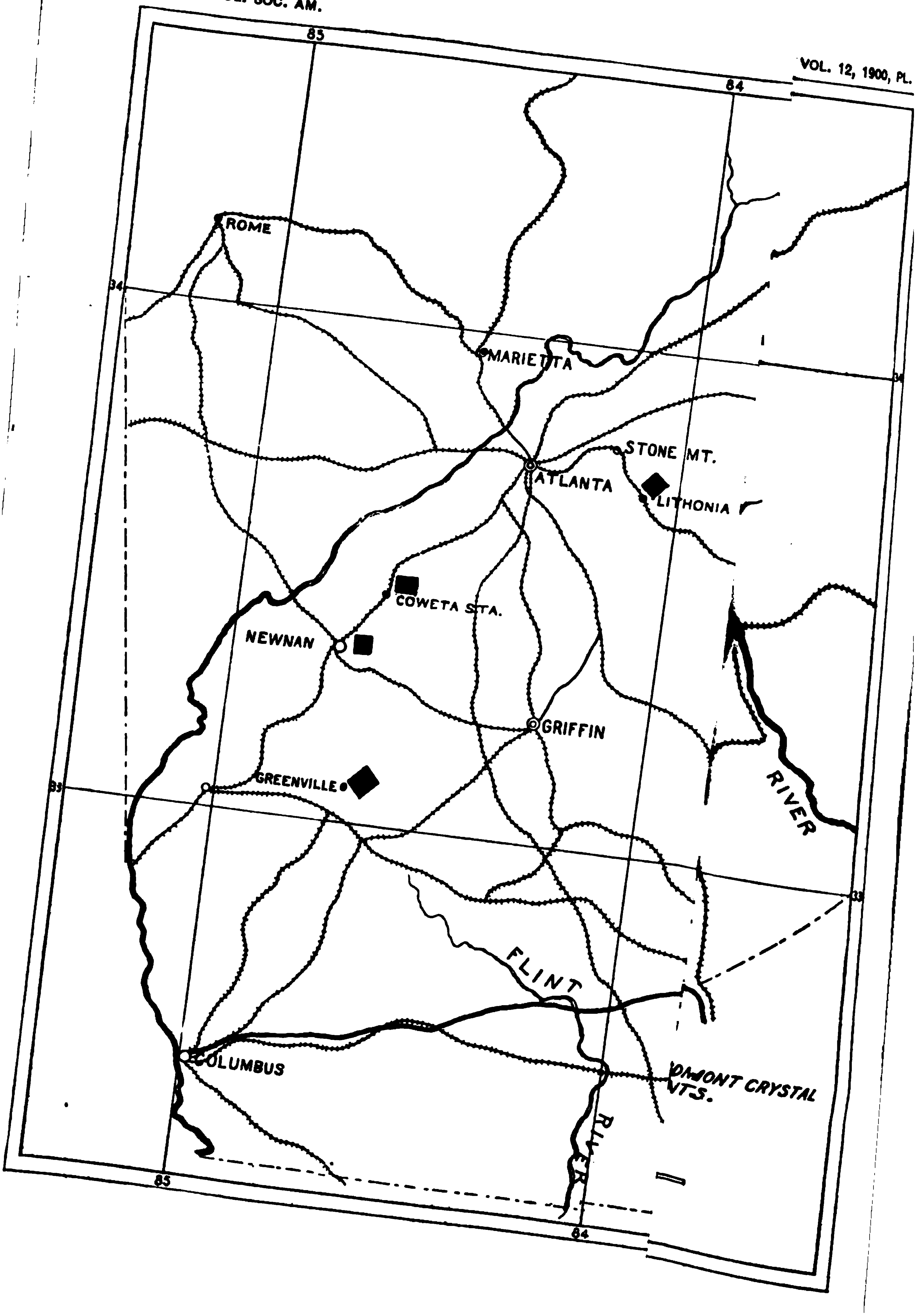
In conclusion, what appear to be the most striking points evidenced by the geological record of this northern part of the Cordillera perhaps be specified as follows:

(1) The great thickness of strata accumulated both to the east and west of an Archean axis. In the Laramide geosyncline the strata no doubt actually attained the volume stated. In the western and wider syncline it is not so certain that all the formations in their full thickness were ever actually superposed at any one place or time (for reasons already alluded to), but the volume was probably not less than in the Laramide region.

(2) The great proportion of volcanic materials accumulated in the western geosyncline and the recurrence of vulcanism throughout the geological time-scale in this region, resulting in the production of massive volcanic formations in the Cambrian, Carboniferous, Triassic, Cretaceous, and Miocene.

(3) The recurrence of folding and disturbance parallel to the border of the Pacific basin and the concurrent great changes in elevation of the land relatively to the sea, both continued down to quite recent geological times, the latter even into the Pleistocene.

(4) The tremendous energy of denudation, in part due to the events last referred to, but also dependent upon the position of the region on the eastern border of a great ocean, where, in northern latitudes, an excessive rainfall must have occurred at all periods on the seaward mountain ranges. No comparable denuding forces were probably ever operative on the east side of the continent in similar latitudes since the definition of the ocean basins of the Pacific and Atlantic.


85
84
34
33
ROME
MARIETTA
STONE MT.
ATLANTA
LITHONIA
COWETA STA.
NEWNAN
GRIFFIN
GREENVILLE
RIVER
FLINT
COLUMBUS
RIVER
85
84

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 93-108, PLS. 6-11 FEBRUARY 26, 1901

WEATHERING OF GRANITIC ROCKS OF GEORGIA *

BY THOMAS L. WATSON

(*Read before the Society December 29, 1900*)

CONTENTS

INTRODUCTION †

For the past three years the writer has been engaged in a careful detailed study of the granitic rocks of Georgia, giving special attention to the phenomena of their weathering. The natural outcrops have been carefully studied in the field, and specimens of the fresh and weathered rock, representing various stages in the decay, have been collected from the most typical and widely separated localities in the state and analyzed in the chemical laboratory of the State survey by the writer. The material is sufficiently representative and the work extensive and detailed enough to arrive at definite conclusions regarding the changes involved in the transition from fresh to decayed rock in the granitic group of rocks.

Based primarily on texture and structure, three types of the granitic rocks are distinguished: (1) The massive even-granular granites; (2) the

* Published by permission of the State Geologist of Georgia.

† For a detailed discussion of the weathering of the Georgia granites, including complete chemical analyses of the fresh and accompanying decayed rock from numerous localities in the state, the reader is referred to a report on the granites and gneisses of Georgia, to be issued shortly by the State Geological Survey, by the present author.

porphyritic granites, and (3) the banded or foliated granites—gneisses. Laboratory study shows the three types to be nearly identical in mineral and chemical composition. In the field, the porphyritic facies of the granite masses are found to grade peripherally into an even-granular, medium, coarse textured granite of the same mineral and chemical composition. Likewise the gneisses are elsewhere shown to be the metamorphosed equivalents of the irruptive massive granites from which they differ only in a pronounced banded or foliated structure, secondarily induced by metamorphism. For this reason the gneisses are referred to as granite-gneisses. That comparisons may be effected and emphasis given, whatever differences arising from the influence of texture on weathering, as illustrated by the degeneration of the Georgia granitic rocks, the rock-decay is separately treated under (1) granite; (2) porphyritic granite; and (3) granite-gneiss. The several places described in the following pages are shown on the accompanying map, plate 6.

Granite

CHARACTER AND COMPOSITION

The fresh unaltered granites are massive, fine to medium grained rocks in texture, light gray to dark-blue gray in color, and show an admixture of fine, granular quartz, feldspars, and biotite to the unaided eye. The principal minerals are quartz, orthoclase with microperthitic structures, microcline, plagioclase near oligoclase, brown biotite, some muscovite, and a little apatite, zircon, and magnetite.

The quartz is frequently intergrown with the feldspar in the form of rounded ovals or disks of micropegmatitic structures, clearly indicating the contemporaneous crystallization of the two minerals. It is sometimes inclosed as drop-like inclusions in many of the larger feldspar crystals. The larger individuals further show numerous lines of fracture and undulatory extinction.

The potash feldspars usually show good cleavages; are intergrown with a second feldspar, albite, as microperthitic intergrowths, and are commonly twinned according to the Carlsbad law. The presence of considerable soda in the analyses corroborates the inference that the intergrown feldspar with the potash varieties is albite. Microcline varies in quantity, but may equal or even exceed in a few sections the orthoclase. Plagioclase is inferior in amount to the potash feldspars, and, as a rule, affords low extinction angles in basal sections, indicating an acid feldspar near oligoclase. This inference is corroborated by the percentage of lime shown in the analyses. The biotite is deep brown in color and strongly pleochroic. It is present in irregular shreds and elongated

FIGURE 1.—GRANITE QUARRY NEAR GREENVILLE, GEORGIA

Showing gradation from residual clay to fresh granite and illustrating method of granite weathering

FIGURE 2.—GULLIED SLOPE IN DEEP RED PLASTIC CLAY DERIVED FROM FRESH GRANITE

GRANITE QUARRY AND ERODED SURFACE IN RESIDUAL CLAY

plates, with good crystallographic boundaries, and intimately associated with muscovite when present. A part of the biotite is invariably partially altered to chlorite. Muscovite varies in quantity, and is always inferior in amount to the biotite. Epidote is somewhat abundant as a secondary constituent in some of the granites. The remaining microscopic accessories present show the usual characteristic features.

The first decided change in the weathering of the massive granites, in which an almost complete change in appearance from the perfectly fresh granite is indicated, is represented by a hard and firm, dull grayish granitic mass, tinged from a faint to a highly ferruginous rusty brown color. It varies in tenacity from the firm, hard rock to specimens which readily crumble under the gentlest pressure. Aside from change of color and lack of luster in the component minerals, the rock has lost its compact, close grained texture, and the partially changed granite presents instead a somewhat spongy or loose texture in appearance, in which the individual mineral grains are slightly forced apart from each other. The feldspars are of a decided white color, perfectly opaque to the naked eye, and have commenced to split along the cleavage planes. Under the lens, the feldspars show comparatively fresh luster in places; the biotite appears somewhat leached from hydration and oxidation, and the adjacent areas are slightly discolored from the hydrous iron oxide derived therefrom. In the center of the biotite plates the luster on the cleavage faces is as brilliant and the color as strong as that in the fresh rock. Thin-sections made from hand specimens representing this stage in the weathered rock show a marked yellow color to the naked eye, indicative of the iron oxide staining derived from the decomposition of the biotite.

A microscopic examination of the thin-sections confirms the above macroscopic description. Under the microscope the feldspars appear somewhat cloudy and opaque, but otherwise are comparatively fresh looking. The plagioclase feldspars are more altered, as a rule, than the potash varieties. The alteration takes place mostly along the twinning planes in the plagioclase, and mainly along the lines of cleavage in the potash feldspars. The only visible change in the quartz is a splitting up along the innumerable fracture lines subsequently induced through dynamic action. The quartz and feldspar areas, particularly along the lines of cleavage and breakage, are stained yellow by the hydrous iron oxide derived from the partial decomposition of the biotite.

The biotite appears in part perfectly fresh, but a large proportion of this mineral has lost its cleavage and optical properties, and is replaced by an amorphous yellow to brown colored mass, with the surrounding areas partially discolored from the ferruginous constituent. In still other shreds of the biotite the edges and borders are frayed out and leached,

while the centers remain entirely fresh. As observed in the potash feldspars, alteration takes place in the biotite to a marked degree along the cleavage planes.

No calcite has been observed in any of the thin-sections of the partially decomposed rock under the microscope; and the further absence of carbonates in the residual granite-decay was proved by testing portions of the finely powdered rock in dilute acid.

Digestions of separate portions of the residual products, in various stages of decomposition, in very dilute HCl at the temperature of boiling water, gave solutions varying from slightly colored to a deep wine-red in color, according to the extent of decay and the amount of iron oxide liberated from the iron-bearing silicate minerals and retained in the residual product. The residues from these separately treated portions of decayed rock indicated, according to the degree of decay, varying amounts of the fresh and partially fresh minerals, quartz, feldspar, and biotite. Numerous magnetite grains, just as fresh apparently as in the unaltered granite, were found to some extent in all the residues. In the advanced stages of decay, represented by highly ferruginous red-colored plastic clays distinctly gritty in feeling, owing to the presence of free quartz and partially decayed silicate minerals, the biotite shreds are changed from black, highly lustrous plates in the fresh granite to brittle brass-colored foliæ in the ferruginous clay, and are slowly soluble in both cold and hot dilute acid.

DISCUSSION OF THE CHEMICAL ANALYSES

Five widely separated sections of the massive even-granular granites were selected for making chemical analyses of the fresh and corresponding decayed rock for purposes of illustrating the changes accompanying the transition in weathering. The residual product represented stages of decay, varying from distinctly discolored, hard and firm rock to highly ferruginous red plastic clays. A careful study of the tables of analyses, representing the rocks in various stages of decay, shows the principal features in the change from fresh to decayed granite. On the assumption of constant Fe_2O_3 the following calculated maximum and minimum percentage amounts of each constituent have been retained or saved, according to the corresponding stage in decay:

	Maximum	Minimum
SiO_2	92.20	22.80
Al_2O_3	99.37	56.18
CaO	57.28	1.18
MgO	84.21	12.06
Na_2O	85.86	7.85
K_2O	96.60	8.26

Figure 1.—Twenty-foot Section of residual Clay derived from porphyritic Granite

Along public road, near depot, Chatham, Virginia

Figure 2.—Gullied Surface in residual Clay of porphyritic Granite

Near Depot, Chatham, Virginia

RESIDUAL CLAYS DERIVED FROM A FOLIATED BIOTITE PORPHYRITIC GRANITE

The transition from fresh to decayed granite is accompanied in every case by a gain in H_2O, which increases in amount proportional to the stage in weathering. The percentage loss for the entire rock is also proportional to the degree of decay reached in the residual product. The amount lost for the entire rock varies from 8.14 to 71.82 per cents respectively. The figures further indicate that the early stages in weathering are mostly in the nature of disintegration, while the chemical forces—decomposition—become the principal agents in the transformation in the later stages. The residual soils are accordingly gray in color and principally sandy, or deep red in color and principally clayey.

Porphyritic Granite

CHARACTER AND COMPOSITION

Three of the largest and most typical porphyritic granite areas were selected for indicating the processes involved in the weathering of this type of rock in Georgia. Two of the areas represent the massive porphyritic granite, while the third is a pronounced foliated type of the same rock.

This type of granite only differs from the equivalent even-granular facies in porphyritic structure, and, as a rule, somewhat coarser grained in texture. The porphyritic texture grades, in most cases, into the even-granular granite facies peripherally, with no difference shown in mineral and chemical composition. They consist of a coarse grained granite matrix of quartz, feldspar, and biotite, in which are imbedded potash feldspar phenocrysts 10 to 50 millimeters long and 5 to 10 millimeters across; idiomorphic to allotriomorphic in crystal outline, with pronounced cleavages parallel to (001) and (010), and are twinned according to the simple type of Carlsbad twins.

The weathering of the natural rock exposures in the field is in every way analogous to that of the massive granites, with usually no visible difference apparent between the two, on textural grounds. The chemical changes accompanying the transition from fresh to decayed rock are closely similar in the two types of granite.

DISCUSSION OF THE CHEMICAL ANALYSES

The principal features to which attention need here be called are (1) a gain in H_2O, which increases as the change becomes more advanced; (2) a total percentage loss for the entire rock, varying, according to the

completeness of the change, from 15.84 to 35.07 per cents respectively; (3) the transition from fresh to decayed granite has been accompanied by the retention of the following maximum and minimum percentage amounts of each constituent saved:

	Maximum	Minimum
SiO_2	81.72	60.64
Al_2O_3	92.51	89.11
CaO	86.64	3.71
MgO	69.04	58.23
Na_2O	91.29	26.26
K_2O	93.16	52.18

Granite-gneiss

The Lithonia area of contorted gneiss in DeKalb county best illustrates the character of and changes incidental to the weathering common to this type of rock in Georgia. It has been shown elsewhere by the writer that the gneisses of Piedmont, Georgia, are closely similar to the granites in chemical and mineralogical composition, and are accordingly metamorphosed granites. The gneisses are only distinguished from the massive granites by a pronounced banded or schistose structure subsequently induced by metamorphism. They are therefore designated granite-gneisses in contradistinction to gneisses of known sedimentary origin.

The sap (partially decayed surface rock) of the doming masses of Lithonia granite-gneiss and the adjacent famous Stone Mountain granite boss is very thin, rarely averaging, as a rule, more than two inches in thickness. It is hard and firm surface rock, discolored a slight red from the partial hydration and oxidation of the biotite. The feldspars are dull and opaque from kaolinization, and in most cases the rock indicates alteration to a greater depth than the discolored portion, manifested by general dullness in appearance of the stone through more or less feldspathic alteration. Numerous exposed sections of apparently completely disintegrated and decomposed granite-gneiss are exposed, varying in depth from 10 to 15 feet, with the schistosity of the original fresh rock almost perfectly preserved in the residual clays forming the sections.

Microscopically the gneisses are composed of quartz, orthoclase and microcline, intergrown with a second feldspar, albite in the form of microperthitic intergrowths, an acid plagioclase near oligoclase, and biotite. A little magnetite, garnet, some apatite, and zircon are present.

Figure 1.—Complexly contorted gneissic Bands or Layers

Figure 2.—Another Type of variation in structure of the Gneiss

GRANITE-GNEISS, LITHONIA, GEORGIA

FIGURE 1.—THIRTY-FOOT SECTION OF VARICOLORED RESIDUAL CLAY

Derived from decay of gneiss

FIGURE 2.—FORTY-FOOT SECTION OF RESIDUAL CLAY

Derived from decay of gneiss. Original schistosity planes of fresh rock perfectly preserved

RESIDUAL CLAYS DERIVED FROM DECAY OF GNEISS, NEAR ATLANTA, GEORGIA

More or less chlorite, muscovite, and epidote occur as secondary minerals derived from the alteration of the feldspars and biotite. The potash feldspars predominate and the species vary in amount from place to place. Microcline is somewhat more abundant than in the even-granular granites and their equivalent porphyritic facies. The plagioclase also varies in amount. The chemical analyses corroborate the inference that the plagioclase is oligoclase in the percentage of lime present. They further indicate a larger percentage of free quartz than the massive granites and their porphyritic facies, which is confirmed by the microscope. Slight peripheral shattering of the larger quartz and feldspar crystals, numerous lines of fracture, and wavy extinction common to these two minerals afford evidence of the effects of dynamometamorphism.

The physical and chemical changes involved in the processes of decay of the gneisses are strikingly similar to those of the granite types.

RÉSUMÉ

The following conclusions are based on the percentage amounts saved and lost per each constituent, and the total loss for the entire rock, calculated from the analyses of the fresh and corresponding decayed rock, on an assumed Fe_2O_3 constant factor.

A careful study of the tables of chemical analyses of the fresh rocks and their corresponding decayed products shows the amount of water to rapidly increase as the decomposition advances, which, as Merrill* has shown, becomes the most important factor in the earlier stages of rock weathering. The change has in every case been accompanied by a loss in the silica, a proportional greater loss in the alkalies, lime, and magnesia, with a proportional increase in the iron oxide, and in some cases in the alumina.

The decayed product of the Georgia granites invariably show an abundance of quartz grains derived from the free quartz in the fresh granite. In most cases the quartz granules have been only slightly corroded and are prevailingly angular in outline. Frequent examination of the quartz grains in the residual clays was made under the microscope for evidence of etching and solution, but positive evidence was lacking in every case. The loss, therefore, in this constituent in the Georgia granites has been derived in large part, if not entirely, from the silicate-bearing minerals, feldspar and biotite, which was doubtless removed with the alkaline solu-

* Rocks, Rock Weathering, and Soils, New York, 1897, p. 234.

tion of the more soluble constituents, as liberated in the free-nascent state. It has been shown,* however, that rocks composed of silicate minerals, almost or entirely lacking in alkalies, lost a portion of their silica with equal readiness. This has been explained on the supposition that as the silica was liberated in the nascent state it was soluble either in pure or carbonated water.

The iron is mostly present in these rocks in the form of ferrous iron. The stability of this constituent characterizing all the analyses of the fresh and decayed rocks may be readily accounted for on the supposition that the decomposition was promoted in a sufficient supply of oxygen, whereby all of the iron was converted into the form of insoluble hydrated sesquioxide and retained with the residue. The analyses indicate only a slight loss in most cases in the alumina, while in others it has all been retained in the transition from the fresh to the decayed rock.

The lime, magnesia, and alkalies obey the usual laws in the proportional amounts lost and saved for such rocks. The lime has invariably disappeared in larger percentage amounts than the magnesia, and likewise the sodium salts have been removed, as a rule, in larger quantities than those of potassium. The feldspars are, of course, the principal source of the soda and potash in the rocks, and the removal of soda in larger amounts than the potash indicates that the potash feldspar varieties are more refractory toward normal atmospheric agencies than the soda-lime or plagioclase varieties.†

The accessories—tourmaline, magnetite, zircon, and garnet—all occur to some extent in the residual granite sands scarcely affected at all by the atmospheric agents.

In the most advanced stages of decay the residual product is a highly plastic ferruginous clay, rendered gritty from the presence of free quartz granules mainly, along with a small percentage amount of the undecomposed silicate minerals. In such cases the transition from fresh to decomposed rock has been accompanied by an unusually large proportional loss in the constituents, greatly exceeding in several instances 50 per cent.‡ In these cases the change is not far from complete, as shown, not only in the chemical analyses, but in the relatively small amounts of undecomposed minerals present in the clay as well. Where the change

* Ebelmen: Ann. des Mines, 1845, vol. vii.
Merrill, Geo. P.: Op. cit., pp. 226, 227.

† Roth's Allegemeine u. Chemische Geologie, 3d edition, 2d heft. Geldmacher M., Beitrage zur Verwitterung der Porphyre, Leipzig, 1889. Lemberg, Zeit. der Deut. Geol. Gesellschaft, 1876, p. 28.

‡ Merrill, Geo. P.: Rocks, Rock Weathering, and Soils, New York, 1897, p. 234.

is accompanied by so large a total loss in the constituents for the entire rock, the process is an advanced one and entirely in the nature of chemical decomposition. In the earlier stages of weathering the rock begins to crumble and is ultimately reduced to a light gray-colored granitic sand, through hydration and temperature changes—disintegration—accompanied by only slight chemical change. The following summary of results, showing the total percentage loss of constituents for the entire rock in the various stages of decay, as calculated from the analyses, will indicate to some extent whether the process involved has been mainly one of decomposition or disintegration:

Locality.	Total loss for entire rock.
Average of analyses from the Crossley and Southern Granite Company's quarries	7.68
Swift and Wilcox quarry, near Elberton	7.92
Coggin's Granite Company's quarry, near Oglesby	8.14
The Lexington Blue Granite quarry, near Lexington	14.56
Heggie Rock, Columbia county	15.84
Crossley quarry, near Lithonia	26.49
Brinkley place, near Camak	34.04
McCollum quarry, Coweta county	35.07
Coggin's Granite Company's quarry, near Oglesby	36.38
Cole quarry, near Newnan	38.48
Greenville Granite Company's quarry, near Greenville	61.85
Greenville Granite Company's quarry, near Greenville	71.82

In the Georgia granitic rocks, it is observed that in some localities the biotite begins to give way first, while in others the feldspar appears to be the most affected; and in others still the rate of decomposition is seemingly about equal for the two minerals. The problem is somewhat complicated, however, in the case of the Georgia rocks, owing to the large proportion of plagioclase, soda-lime, feldspar present, and the abundance of microperthitic structures common to the potash feldspar varieties.

During the early stages of weathering in these rocks chemical decomposition is subordinated to physical disintegration, and the rocks have suffered mainly through temperature changes, such as produce granulation and weakening in the adhesive power between the individual minerals—feldspar and biotite—resulting in crumbling along the planes of cleavage. Freezing and solution have aided in the process, but owing to the low absorptive power of the Georgia rocks, they can not be con-

sidered as essential factors. The following tabular statement shows the percentage or ratio of absorption for the Georgia granites, determined by the writer in the laboratory of the State survey:

Locality.	Gain in absorbed water.	Percentage of absorption.
The Charley Rocker quarry, Hancock county	0.04	0.037
The Sparta quarry, Hancock county	0.04	0.049
The Lexington Blue Granite quarry, Oglethorpe county.	0.08	0.092
The Diamond Blue Granite Company's quarry, Oglethorpe county	0.11	0.088
The Swift and Wilcox quarry, Elbert county	0.08	0.090
The Wright place, Elbert county	0.09	0.092
Tate and Oliver quarry, Elbert county	0.08	0.093
Coggin's Granite Company's quarry, Elbert county	0.15	0.090
The Childs's quarry, Elbert county	0.17	0.092
The Snell quarry, Gwinnett county	0.10	0.075
The Linch quarry, Putnam county	0.04	0.060
Greenville Granite Company's quarry, Greenville	0.11	0.086
The Odessa quarry, Meriwether county	0.05	0.056
Stone Mountain Granite quarries	0.09	0.067
Arabia Mountain Granite quarries	0.04	0.050
Pine Mountain Granite quarries	0.06	0.073

The fact that granitic rocks may undergo extensive disintegration with but slight decomposition has been emphasized by several writers.* Numerous cases where the rocks have been resolved into residual products from disintegration with little decomposition, and also where decomposition follows so closely on disintegration, the former greatly predominating, are well illustrated among the various types of the Georgia granites. The data are yet insufficient, however, to draw any definite conclusions concerning the difference in weathering, if there be any, between the fine and coarse grained granites of the state; that is, to state definitely whether the coarse grained varieties suffer mainly from disintegration and the fine grained ones by disintegration closely followed by decomposition.

The early stages in the processes of weathering, as elsewhere pointed out in this paper, for each type, fine and coarse grained, of the Georgia

* Voyage of the Vega, 1881, vol. ii, p. 420. Quoted by Merrill, Geo. P., op. cit., p. 242. Bull. Geol. Soc. Am., 1895, vol. 6, pp. 321–332; also, Rocks, Rock Weathering, and Soils, 1897, pp. 206–213; Rocks, Rock Weathering, and Soils, 1897, p. 243.

rocks is mainly one of disintegration accompanied by some chemical change, while the later stages are as prevailingly characterized by decomposition, resulting in the production of a stiff, plastic red clay. The earlier stages in the weathering of the fine grained granite are apparently the same as for the similar stages in the coarse grained porphyritic granites. The same statement holds for the two types in the advanced stages of weathering—decomposition. The striking similarity in the granite, porphyritic granite, and gneiss, as relating to solubility in acids, is well illustrated in the percentage amounts of soluble matter extracted from weighed portions of the finely powdered fresh rock, by digestion in 100 cc. of half normal HCl for three hours, at the temperature of boiling water.

Granites	Per cent of soluble matter.
The Oglesby blue granite, Elbert county	10.56
The Hutchins blue granite, Oglethorpe county	9.77
Swift and Wilcox light gray granite, Elbert county	9.20
Echol's mill light gray granite, Oglethorpe county	8.37
Average	9.475
Porphyritic Granite	
Heggie Rock, Columbia county	10.98
Heggie Rock, Columbia county (decay)	12.69
Brinkley place, near Camak	16.29
Brinkley place, near Camak (decay)	23.69
Porphyritic granite near Line creek, Fayette county	9.47
Average of fresh rock	12.246
Granite-gneiss	
Southern Granite Company's quarry, near Lithonia	7.58
Arabia Mountain quarries, De Kalb county	6.06
Tilley quarry, Rockdale county	5.94
Average	6.526

The lower percentage of soluble matter in the granite-gneisses over the granites and their porphyritic facies is readily accounted for on the basis of this rock type containing a larger amount of free quartz, as shown in the chemical analyses. The inference is also corroborated by microscopic study. In each case where the total percentage of extract from

the decayed rock was determined an increase over the corresponding extract from the fresh rock was indicated.*

Cause of red Color of the Soil

The cause of color variation in soils has been discussed in recent years by Crosby,† Dana,‡ Russell, § and Merrill.|| Thus far the writer's observations are in accord with those of Crosby and Merrill in supposing this to be a superficial phenomenon. The most brilliant hues are observed to be confined to the immediate surface portions, varying from an inch to many feet in depth, which gradually give way in turn to more modest hues of yellow and brown, and finally pass into the grays and other colors of the fresh parent rock beneath, as the depth increases. Such a transition may be observed in almost any recent excavation in the crystalline belt of the southern Appalachians. There are, however, two exceptions to this which without proper differentiation will prove very misleading:

(1) In those cases where the sections have been exposed for some time the transition in vertical section becomes quickly obscured by the washing down of the brilliant ochreous coloring matter from above, frequently coating the section face to the entire depth of exposure with a varying thickness of the ferruginous wash of apparently the same degree of color. This invariably happens, and may be observed to advantage after heavy rains in almost any part of the above belt.

(2) In still other cases exceptions are to be found in the weathering along the joint planes and other approximately vertical as well as horizontal planes of weakness found cutting the rock masses. In these the color is most intense along the immediate surface of the planes, and extends oftentimes, in case of the vertical planes, to a considerable depth.

Crosby is inclined to regard the increase in color of the superficial portions to be due wholly to dehydration of the ferric salts, while Merrill recognizes not merely the *quality* of the coloring matter, but emphasizes the importance of *quantity* as well. Merrill ¶ says: "This is well

---

* Geo. P. Merrill: Op. cit., 1897, p. 219; Bull. Geol. Soc. Am., 1896, vol. 7, pp. 349–362.

† W. O. Crosby: Proceedings Boston Soc. Nat. Hist., 1884–1888 (1888), vol. xxiii, pp. 219–222; Technological Quarterly, 1891, vol. iv, p. 36.

‡ J. D. Dana: Amer. Jour. Sci., 1890, xxxix, pp. 317–319.

§ I. C. Russell: U. S. Geol. Survey, Bulletin no. 52, 1889, 65 pp.

|| Geo. P. Merrill: Bull. Geol. Soc. Am., 1897, vol. 8, pp. 161–162; Rocks, Rock Weathering and Soils, 1897, pp. 384–386.

¶ Bull. Geol. Soc. Am., 1897, vol. 8, p. 162.

shown in the fractional separations made by washing these residual clays and sands, whereby they are separated into proportional parts of varying degrees of fineness." It has been recently shown in climates where rock weathering is accompanied by a leaching process, in which the more soluble constituents are more or less gradually removed in solution, the ferric and alumina salts are found to be the most refractory of the essential constituents in igneous rocks. The resulting final product of decomposition consists therefore of a highly ferruginous clay, composed mainly of the hydrated aluminous silicates, free iron sesquioxides, and, in the case of acid rocks, additional free silica.

Merrill * remarks that, all things being equal, the depth or degree of color indicates advanced decomposition and also geological age. This statement accords well with the writer's work on the Georgia granites. The gray soils derived from the granitoid rocks of the state represent not an advanced stage of decomposition, but mainly a process of disintegration manifested in the partial kaolinization of the feldspars and a slight rusting, oxidation of the biotite; while the red soils derived from the same rocks are invariably deep, red ferruginous clays in which the biotite is thoroughly leached and oxidized and the feldspars nearly, if not entirely, kaolinized. Stated somewhat differently, the gray soils contain an abundance of all the component minerals present in the fresh rock, but slightly altered chemically; are highly porous, sandy soils, from which clay is essentially absent, and have been derived from the fresh rock chiefly by disintegration. The red soils, on the other hand, contain comparatively only a very small percentage of the undecomposed silicate minerals; are deep red, ferruginous, stiff clays, rendered more or less gritty from the presence of free quartz, and have resulted from decomposition. The gray soils represent, therefore, the earlier stages, disintegration, in the weathering of the rocks, while the red soils are conversely the products of decomposition and represent the advanced stages in the change.

While quantity of pigment—ferric oxide—seemingly controls or rather accounts for the brilliant coloring of the soils in general, conditions afford strong indications, at least, of the suggestion of presence of some other factor or factors of marked importance. In support of this statement the author has critically examined all available authentic analyses of the decayed rock products and carefully noted each writer's description as to color. One or two illustrations will suffice:

Dr Merrill † has described the weathering of a micaceous gneiss from Albemarle county, Virginia, the decayed product — residual soil — of

* Rocks, Rock Weathering, and Soils, 1897, p. 386.
† Bull. Geol. Soc. Am., 1897, vol. 8, pp. 157-168.

which he characterizes as "highly plastic" and "deep, red-brown" in color, yielding on chemical analysis 12.18 per cent of Fe_2O_3.

The writer (Watson) has described elsewhere the changes incident to the weathering of an even grained granite near Greenville, Meriwether county, Georgia, the accompanying residual product from which is a highly ferruginous deep red, dark colored, stiff, plastic clay, slightly gritty, chiefly from free quartz, and yielding on chemical analysis only 6.33 per cent of Fe_2O_3.

Still another case in question is the weathering of a similar fine and even grained granite near Newnan, Georgia. The residual product from this granite is a clayey mass, less plastic and not so dark in color as the Greenville material, but is a bright cherry-red in color, and yields only 1.91 per cent of Fe_2O_3 on analysis. Practically the same results are shown on comparing the recorded results of basic igneous rocks. According to these data, we apparently have residual products of essentially the same character and depth of color, but varying evidently in the amount of coloring matter—ferric oxide—present. The two extremes are represented by 12.18 and 1.91 per cents respectively, the former containing more than six times the amount of ferric oxide shown in the latter, and yet the same results as regards color are seemingly produced.

Results based on assumptively insoluble Al_2O_3 and $Al_2O_3 + Fe_2O_3$

It has been shown* that of the essential constituents in silicious crystalline rocks the iron and aluminum oxides are the most refractory, and accordingly the least likely to suffer loss during the processes of rock degeneration. The work of Dunnington,† Clarke,‡ and Smyth § strongly indicates concentration, instead of loss, in titanium, in the residual product derived from the titanium-bearing minerals, upon weathering. This element occurs so sparingly distributed through the acid crystalline rocks, averaging, as a rule, less than 0.5 of 1 per cent, that it can not be regarded as a safe basis of assumption for calculating the percentage amounts of the more essential constituents saved and lost present in the rock. The same statement, as regards concentration instead of loss, also applies in some cases to several other ones of the accessory minerals sometimes present.

* Merrill, Geo. P., op. cit.

† Amer. Jour. Sci. (3d ser.), xli, pp. 491–495.

‡ U. S. Geol. Survey, Bulletin no. 78, pp. 34–42.

§ Bull. Geol. Soc. Am., 1898, vol. 9, pp. 257–269.

In the Georgia granitic rocks the iron and aluminum oxides have proved the most resistant of the constituents present toward the weathering agents, and while the ratio of increase for the two is nearly the same, that of the iron is, with several exceptions, slightly greater than alumina, and has therefore been assumed to remain constant for convenience of comparison of the analyses of the fresh and decayed rock in tables I, II, V, VI, VIII, and IX. The figures in the tables of analyses disclose the fact that the percentage of iron oxide in the fresh and decayed rock is strikingly smaller than that of the alumina. While the ratio of increase in the iron oxide, as pointed out above, is slightly greater than that of the alumina for the decayed and fresh rock, the writer has recalculated in a similar manner all of the results: first, on the assumption of an Al_2O_3 constant basis; and, second, on the assumption of an $Al_2O_3 + Fe_2O_3$ constant basis in order to make comparisons and point out the possible differences resulting. The percentage amount of alumina is greater in every case of the Georgia granites for the decayed product than for the corresponding fresh rock, and is present in larger amounts than any other single constituent where increase in the decayed over the fresh rock is indicated. Briefly stated, a comparative study of the tables based on the assumption of, first, an Al_2O_3, and next, an $Al_2O_3 + Fe_2O_3$ constant, shows:

1. That on the assumption of constant Al_2O_3, the Fe_2O_3 like the H_2O indicates a slight gain, owing to the ratio of increase being greater for the iron oxide than for the alumina.

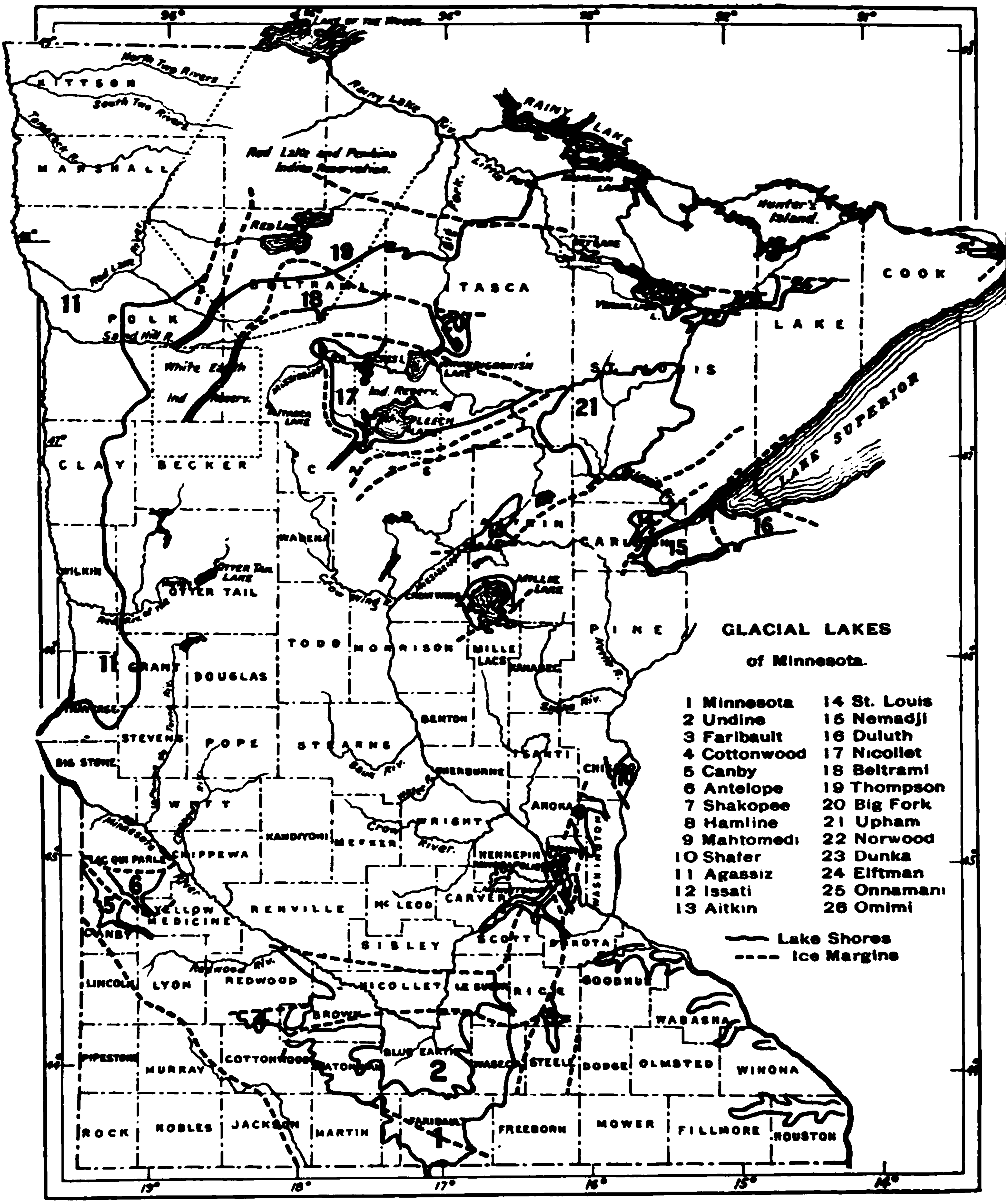
2. The calculated percentage amounts of the constituents saved and lost are in similar ratios for the three cases, but differ in actual amounts in each one. The constituent showing the greatest loss under one assumed constant likewise indicates similar loss for the other two assumptions. The percentage amount lost or saved for any one constituent is not the same in the three cases.

3. The total percentage loss for the entire rock is invariably greater on the assumption of an Fe_2O_3 constant than for the other two assumptively insoluble constituents. In each case the lime salts have been removed in larger amounts than the magnesia, and similarly the soda has suffered a greater loss than the potash. The fact particularly emphasized is the greater loss for the entire rock on the Fe_2O_3 assumed constant over that of the Al_2O_3 and $Al_2O_3 + Fe_2O_3$ assumptions.

The tables show that the conclusions stated under 2 and 3 are governed directly by the numerical value of the ratio of increase—factor—of the constituent assumed to remain constant in the change from fresh to residual rock.

The losses for the entire rock, based on the three assumptively insoluble constituents, are tabulated below for convenience of comparison :

Table.	Fe_2O_3 constant.	Al_2O_3 constant.	$Al_2O_3+Fe_2O_3$ constant.
I	8.14 44.52	7.40 33.63	6.73 34.29
II	14.56	7.78	8.43
III	....	7.92	7.92
IV	....	38.48	33.72
V	61.85 71.82	43.60 51.64	44.41 52.90
VI	15.84	5.59	6.65
VII	....	34.04	34.04
VIII	35.07	29.88	30.33
IX	26.49	21.10	21.61
X	....	7.68	7.08



GLACIAL LAKES OF MINNESOTA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 109-128, PL. 12 FEBRUARY 28, 1901

GLACIAL LAKES OF MINNESOTA

BY N. H. WINCHELL

(Read before the Society December 28, 1900)

CONTENTS

INTRODUCTION

The reviewing and abstracting of the chapters of the final report of the Geological Survey of Minnesota, so far as they treat of the areal geology

of the state, have brought vividly to mind some of the general physical features which have not been grouped nor discussed in their *ensemble* in any of the chapters of that report. Among these data, which are scattered through the volumes of that report, none stand out more boldly than those pertaining to the drift. After the moraines the glacial lakes are perhaps the most remarkable and most interesting phenomena among the drift features.

In the course of the geological survey most of these lakes have been referred to—at least in respect to some of their features—and some of them have been carefully examined and described. Most of them, however, have not been mapped nor named. The attempt is here made to bring them into one general view, to give each a brief description, and to show its location and approximate size on the accompanying map, plate 12.

Beginning with the southern part of the state, where the first of these lakes must have been formed, they will be enumerated progressively toward the north approximately in the order of their date. The glacial lakes here named reach 26 in number. It is certain that several others might be named which apparently existed incidentally near the outer limits of the Wisconsin ice-lobe, both in the southwestern and in the southeastern part of the state. Reference will be made to some of these in a subsequent paragraph. Excluding such extra-limital lakes, the following will here be described:

Name.	Outlet above the sea. Feet.
1. Lake Minnesota	1150
2. Lake Undine	1020–1070
3. Lake Faribault	1160
4. Lake Cottonwood	1075
5. Lake Canby	1200
6. Lake Antelope	1175
7. Lake Shakopee	875
8. Lake Hamline	940
9. Lake Mahtomedi	950
10. Lake Shafer	975
11. Lake Agassiz	1050
12. Lake Issati	1266
13. Lake Aitkin	1205
14. Lake Saint Louis	1135
15. Lake Nemadji	1070
16. Lake Duluth (or Western Superior Glacial lake)	1055
17. Lake Nicollet	1390
18. Lake Beltrami	1400
19. Lake Thompson	1200
20. Lake Big Fork	1300

Name.	Outlet above the sea. Feet.
21. Lake Upham	1300
22. Lake Norwood	1450
23. Lake Dunka	1495
24. Lake Elftman	1700
25. Lake Onnamani	1370
26. Lake Omimi	1360

It should be further premised that most of these lakes have not been traced out by a continuous following of their beach lines, and some of them probably can not be so defined, owing to their shifting level or their short duration. Their outlets being determined, the same contour lines have been assumed to show sufficiently for this purpose the area and shape of the several lakes.

General Manner of Retreat of the Ice-border

It has been said repeatedly in the reports of the Minnesota survey that the ice came on Minnesota from two directions, from the northeast and from the north-northwest. This is true at least of the glacier bodies that invaded the state. The origination of the nevé which subsequently went to form the glaciers was probably earliest on the high plateaus—that is, on central Minnesota and northwestern Wisconsin. Distinct glaciers formed first and continued longest in the lowlands, and disappeared first from the highlands. In other words, the two great ice-lobes, which deployed first independently and at length confluently and lastly retreated separately, had their central axes along the main depressions. One came southward, up the valley of the Red river of the North, turned southeastwardly down the Minnesota River valley, entered the Des Moines valley, and extended into Iowa. The other originated as a moving, flowing ice mass essentially in the valley of the western end of lake Superior, and in the upper part of the Mississippi valley it became confluent with its western cotemporary, and thence southward they alternatingly advanced on and retreated from each other along a line of contact whose complex and copious morainic accumulations have added great diversity to the drift features of several counties, the difficulties of which have not yet been fully surmounted. These two ice-lobes retreated as they came, one north-northwestwardly and the other east-northeastwardly, and the record which now remains is essentially that produced by this retreat. There was an earlier ice-sheet which extended farther south and which was followed by a period of land surface and vegetation. There is no doubt that that earlier drift surface had some effect

in determining the present general topography, in some such manner as the rocky substructure imprints itself on the present topography, but the legible record with which we have to do in studying the glacial lakes is emphatically that of the Wisconsin epoch, the last which visited Minnesota.

Of these two ice-lobes, that which departed latest from the northern part of the state was the northeastern. As the examination of the state has progressed the recognition of the lake Superior ice-lobe has become more and more pronounced and important. The extent of the westward movement of drift material by this ice-lobe has been traced farther and farther to the west. At the same time the earlier disappearance of the northwestern ice-lobe and its line of retreat rather toward the east-northeast—at least from the extreme northern part of the state—have been pretty well established. It appears that precipitation sufficient for the support of these ice-masses was maintained longer to the north and east of lake Superior than in the plains of the Saskatchewan, and it becomes probable that both ice-lobes sprang from the Laurentide birthplace and were differentiated in direction of flow and in other features after they were gathered into the great valleys where their separate features have been separately studied.

Two conditions have contributed to the formation of glacial lakes in the state and to the ease with which they can be identified and referred to their causes: (*a*) The northward slope of the natural surface in that portion lying north of the continental watershed. (*b*) The duplex character of the drift, namely, the gray till, from the northwest, with its resultant gray modified drift, and the red till, coming from the northeast, with its characteristic red gravels and lacustrine clays.

It was in studying the drift of northwestern Ohio, in 1870 and 1871, that the writer was convinced that the ice was a barrier which ponded back the drainage into the Maumee valley, and he impressed that view on Dr J. S. Newberry, the director of the Ohio survey. The lake thus formed had its outlet into the Wabash valley, and has since been named lake Maumee. On undertaking the Minnesota survey this theory was at once applied to the Red River valley. It has since been widely applied in the northern states, where glacial lakes have been recognized in great numbers. It is probable that many more will be described. It seems almost an invariable law that in valleys sloping toward the north, and hence in general toward the retreating ice-margin, glacial lakes should be formed. By far the larger number of glacial lakes are found to have been due to such conditions. A small number have been due to the oblique transgression of the ice-lobe across a southward sloping broad valley, forcing the river that drained such a valley to set back in the form of a lake until its

surface rose high enough to pass over or round the margin of the ice, or over a low watershed and reach some other route to the sea.

The relations of the gray drift with the red are very interesting. Along a central belt the ice-lobes met at their margins. Sometimes the gray till overlies the red, and sometimes the reverse occurs. In general the gray is on top in the central and southern counties, and in the northern the red till, with its modifications, was latest deposited. Sometimes they alternate several times. This complex marginal belt extends roughly, say, from southern Rice county northward to Minneapolis, thence northwestwardly to Itasca lake, where it turns abruptly eastward, passes through the region of Winnibigoshish lake to the vicinity of Pokegama falls, and thence in general coincides with the Giants range, but leaving that range so as to cross the Pigeon river south of Fowl lake.

1. Lake Minnesota *

This lake was first identified and named by Mr Upham.* As described by him, its outlet was through the Union slough, in Kossuth county, Iowa, at an elevation above the sea of approximately 1,150 feet. This slough occupies a continuous channel from the most southern headwaters of the Blue Earth river to Buffalo creek, a branch of the Des Moines river, its length being about 8 miles. Its width is from one-eighth to one-fourth of a mile, the enclosing bluffs rising steeply from 20 to 30 feet. The surface of the surrounding country is one of undulating till. Near the Minnesota boundary line this channel is deeper, and passes by almost imperceptible changes into the channel eroded in the smooth area covered by the lake since the glacial period by the present drainage.

As will be seen, the area of this lake, which was supposed by Mr Upham to have extended in its greatest extent far toward the northwest, covering nearly all the valley of the present Minnesota river as far as Big Stone lake, is here divided into four lakes, each having its individual outlet at a level somewhat different from that through the Union slough. Even with this reduction it covered the greater part of Faribault, Waseca, and Watonwan counties, and the whole of Blue Earth county, and its depth must have been about 200 feet in the northern part of Blue Earth county. The ice-barrier to which this lake owed its existence was a fluctuating obstruction, and it must have caused occasional important changes in its northern limits. On the plate a dotted line indicates the approximate position of the southern border of the ice

* On the accompanying plate these lakes are indicated by the numbers here applied to them.

† Ninth Annual Report of the Minnesota Geological Survey, p. 341; final report, vol. i, p. 460.

at the time when this lake had its initiation and another when it had its greatest extent. No attempt is made here to correlate this limit with any of the moraines, although it is to be supposed that the main changes and the principal epochs of duration of this and all the other glacial lakes were determined very largely by the main steps of retreat and the stationary epochs of the ice-border.

2. Lake Undine

The Undine region was named by Nicollet.* It embraces the valley of the Mankato river. The later glacial lake to which the name is applied was the descendant of lake Minnesota, and covered part of the same area, but extended from 35 to 40 miles farther north. The outlet of lake Undine was through the Cannon valley in Le Sueur and Rice counties at an elevation of about 1,070 feet, or 80 feet lower than the level of lake Minnesota. It was very near the boundary line between Rice and Le Sueur counties that the waters of this lake began the descent of the Cannon valley eastward to the Mississippi. At the present time the surface of the Cannon river at that point is 994 feet above the sea. The river lies in a valley which is enclosed by gravel terraces which afford an indication of the original height of the Cannon at that point and of the erosion which the gravel has suffered since its first distribution. The highest gravel terrace at the commencement of the outlet of lake Undine requires that the surface of the water at first was at least 1,070 feet, but as this terrace is rather broken and sometimes blends with the till surfaces, it is very evident that this elevation was not long maintained. When the outlet became less obstructed by the glaciers the water of lake Undine acquired a more settled stage, and a second terrace, which is much more marked and persistent than the higher terrace, affords an indication of the approximate level of the water during a much longer period, namely, about 1,020 feet above tide. It is apparent, therefore, that between the date of first acquiring the outlet by way of the Cannon valley and that of a settled stage of outflow the level of lake Undine was lowered by the removal of obstruction by ice and by erosion about 55 feet.

No attempt has been made to trace out the beach lines of lake Undine, but that they could be identified if search were instituted for them, there is little doubt. They would be found running southwestwardly from the outlet in eastern Le Sueur county into the eastern borders of Blue Earth county, westward across that county, where delta deposits would probably be found at the points where the northward-flowing streams

* Final report of the Minnesota Geological Survey, vol. 1, p. 71.

entered lake Undine, which was formed by the transportation and redeposit of the sediments of lake Minnesota. Thence this shoreline must have taken a winding course, with islands and bays, northwestwardly through Watonwan and Brown counties and far into Redwood county, perhaps as far as Redwood falls, as has been indicated by Mr Upham. During this steady stage of this lake the margin of the glacier ran somewhere along a line connecting Scott county with Redwood county. This lake therefore covered Nicollet county and portions of Sibley county, lying on the north side of the Minnesota river. There can hence be no question that these counties owe to this lake their present smoothness of surface and their arable, fertile, loamy soil, which constitute their chief agricultural attractions. Swan lake, in Nicollet county, is the most important residuum of the waters of lake Undine.

3. Lake Faribault

One of the earliest of the glacial lakes of Minnesota was formed by the damming of the waters of Straight river, by the margin of the glacier which ran nearly north and south diagonally across Straight valley. This lake was confined to Rice and Steele counties, and covered the site of the city of Faribault with about 200 feet of water, but it had a rather fluctuating level, as it seems to have escaped sometimes along the eastern margin of the glacier and later across the glacier in Bridgewater, in Rice county, forming the Bridgewater kame. It had for a long time a steady outflow at a level of 1,160 feet above the sea, across eastern Rice county, uniting with the Zumbro river, and thence reaching the Mississippi below lake Pepin.

4. Lake Cottonwood

The extension of lake Minnesota toward the northwest could not have been beyond the point where the contour line of its outlet (1,150 feet) would limit it, nor farther toward the north than the ice-margin at the time of the existence of the lake. There is an abandoned glacial channel in the town of Stately, in western Brown county, running in the line of extension of Big Cottonwood river, the water of which, when flowing, must have had an elevation of about 1,075 feet above the sea. This channel, therefore, must have emptied not into lake Minnesota, but into lake Undine. In order that the Big Cottonwood, or any drainage waters of that vicinity, could have occupied that abandoned channel the glacier margin must have obstructed the natural flow northward, and that would at once produce a small lake which covered the region lying below the level of 1,075 feet, or 75 feet lower than the level of lake Minnesota.

A few miles farther toward the southwest, in Germantown, Cottonwood county, there are two other abandoned watercourses which are at considerably higher altitude, but run in a direction parallel with that in Stately, and these indicate similar relations between the ice-border and the topography, such that the small marginal lakes which they drained probably found their outlets into lake Minnesota. At this time the margin of the ice lay against the northern slope of the quartzite ridge or crossed the ridge, which is here locally known as the eastern spur of the Coteau des Prairies. It is evident that these old channels were the ways of exit of the surface waters which drained the higher region to the south and west—the earliest locations of the Cottonwood river which now reaches the Minnesota river toward the northeast. Below this point the valley of the Cottonwood is much like that of the Maumee river in Ohio below Defiance. The extent of lake Cottonwood to the northward was limited by the ice-border, and toward the south by the Coteau des Prairies, its westward extent being determined by the contour line of 1,075 feet. It hence must have extended sometimes nearly across Redwood county.

5. Lake Canby

About cotemporary with lake Cottonwood, or perhaps somewhat later, the western ice-border produced a similar lake along the northern slope of the Coteau at a point about 70 miles farther northwest, in the western confines of Yellow Medicine county, covering the town of Canby. The area of this lake slopes naturally toward the north, and had it not been obstructed it would have been tributary, as now, to the Lac qui Parle river. The outlet of this lake was by a marked channel, now for the most part not occupied by any stream, which runs southeastwardly parallel with the Coteau des Prairies for a distance of about 15 miles. The bluffs of this channel are 30 to 40 feet high and consist of till. By this channel the water of lake Canby was conducted across a low divide and made to empty itself into the Yellow Medicine river, constituting at that time the chief affluent of that river. Lake Canby had an altitude of about 1,200 feet.

6. Lake Antelope

In the same manner that lake Undine was descended from lake Minnesota was lake Antelope a derivation from lake Canby. The ice-margin receded and afforded a lower outlet. This lower outlet, which was in Yellow Medicine county, town of Omro, also flowed eastward, entering the stream known as Stony run, finally joining the Minnesota river. At the point of exit from lake Antelope the water was at an altitude of about

1,175 feet. This was apparently a short-lived stream, and lake Antelope must be considered only an evanescent incident of the retreat of the ice. The approximate size of this lake is shown on the accompanying plate, having been mostly in Lac qui Parle county.

7. Lake Shakopee

The first of the glacial lakes of the Minnesota valley which may be attributed to the presence of the eastern, or lake Superior, ice-lobe, as distinct from the northwestern ice-lobe, is that which filled the lower reaches of the Minnesota valley from Fort Snelling, or perhaps from south Saint Paul, to the western limits of Scott county. It is named from the city of Shakopee, whose site it covered with about 125 feet of water. It should be remembered, in order to appreciate the complicated features of the drift in this region, that this is near the meridian of the confluence of the two great ice-lobes already referred to. Here an interlobate area was enclosed, partly by the elevated lands to the south and partly by the ice-masses to the northeast and northwest. Evidence is abundant, and has been mentioned in the reports of the Minnesota survey by Mr Upham and by the writer at many places, which shows that this line of confluence was a field of contention between these ice-masses, sometimes one prevailing and sometimes the other, producing a superposition of drift, one kind over the other, one derived from the northwest and the other from the northeast, several times in succession. This is illustrated not only by the alternation of red till with gray, but also by the laminated clays which were produced by the close washing of the tills, as they were gathered by the streams into the contiguous valleys. It must be inferred that by the fluctuation of the ice on one side or the other, the nature of the sediment carried by the affluents of the Minnesota was occasionally changed, or that sedimentation was wholly suspended by the diversion of the drainage to some other point. In order that lake Shakopee should be produced by the western margin of the lake Superior ice-lobe, and yet should contain prevailingly, as it does, a laminated clay derived from the gray till of the western ice-field, it is evident that the western till must have been already deposited and the western ice-field considerably shrunken. The lake Superior lobe here early manifested its tenacity of life and its ability to maintain an independent field of action farther south, at this meridian, than the western ice-lobe. This is a significant relation, and throws light on the later phenomena of this belt of interlobate characters farther toward the northwest.

Lake Shakopee had an elevation of about 875 feet, and at some part of its existence it covered the city of Minneapolis and extended up the

Mississippi valley as far as Monticello, in Wright county; but at the moment of its greatest extension it was also at the epoch of its greatest peril as a lake, a statement which can also be made, probably, of all glacial lakes, for it required but little recession of the ice-border eastward from Mendota to lower the level of the whole lake by exposing a lower outlet. Its first important outlet was through the central part of Dakota county, where a distinct, wide, gravel-terraced valley extends from Crystal lake southeastward and connects with the Vermilion river, which discharges into the Mississippi at Hastings. There are other similar avenues of glacial drainage farther south, in Dakota county, and they may have served as exit for the waters of lake Shakopee in its earliest stages, before it acquired definite characters, and perhaps while the margin of the western ice-lobe took part in giving this lake its northwestern limitation, but they are hardly worthy of separate definition as outlets of distinct glacial lakes.

8. Lake Hamline

Mr Upham has described this lake in the bulletin of the Society.* It was a small lake, confined to a small county (Ramsey), and had a brief existence. It was typically an interlobate lake, and existed slightly prior to lake Shakopee. Its elevation was about 940 feet at first, with an outlet northward, but was soon shifted to about 880 feet, with discharge through Inver Grove, in Dakota county, where it united with one of the later outlets of lake Shakopee. It seems to have suffered by the opening of lower and lower avenues of discharge until it was lowered to the level of lake Shakopee and was wholly lost as an independent lake. It is further probable that the outlets of both lake Hamline and lake Shakopee were occasionally disturbed and shifted in part by the presence of the gorge of the Mississippi at Saint Paul. It is reasonable to suppose that the variations of the glacier where its margin extended north and south across that gorge would afford escape for considerable water from time to time down that valley past Saint Paul. This would occur most frequently during the later portion of the existence of these lakes. The washed drift of lake Hamline is rather coarse, and it sometimes embraces unwashed small pieces of till which indicate the proximity of the ice-margin at the time of deposition of the gravel.

9. Lake Mahtomedi

Lake Mahtomedi covered the region of White Bear lake, in Ramsey county, and extended north into Washington and Anoka counties, hav-

* Op. cit., vol. viii, p. 193, pl. 15.

ing an elevation of 950 feet. It was an incident of the eastward movement of the western ice-lobe after it had retreated to the northwest, the last event of the glacier's occupancy of this part of Minnesota. This readvance has been studied by Mr Upham and fully described by him. According to his interpretation, it was due to an increased precipitation over the central and eastern part of the state, by reason of which glaciers were formed again and had a slow movement southeastward, where they had been absent for a period of time. This lake had an outlet eastwardly in Washington county through Big Marine lake and Cornelian creek to the Saint Croix river, about 6 miles north of Stillwater. The region of this lake is characterized by a modified condition of the till, which is sometimes itself indistinctly stratified, and by laminated clays due to a more complete washing of the till and the deposition of its finest components in thin sedimentary sheets. As the western ice receded again this lake vanished gradually by drainage toward the west, becoming absorbed by a tumultuous flood of gravel-and-sand laden water which passed southwestwardly across Chisago and Anoka counties at a level not much below that of the lake itself.

10. Lake Shafer

The eastern part of Chisago county, as far westward as Center City, shows similar indications of a body of standing water at a date nearly cotemporary with that of lake Mahtomedi, the surface of which was about 975 feet above the sea. It appears that the Saint Croix river was obstructed by the last movement of the toe of the western ice-lobe, below Franconia, and was set back in form of a lake whose outlet was in Wisconsin and has not been discovered. It must have been about the eastern border of the ice.

11. Lake Agassiz

The largest of the glacial lakes in which Minnesota has any record is that named and investigated by Mr Upham. Beginning in Minnesota he followed this investigation into Dakota and then into Canada.* Its outlet, which was at 1,050 feet above the sea, and its location and outline are shown on the accompanying map, plate 12.

Although there may be some variations in the details and sequence of the parts of this great lake, rendered necessary by future researches in the northern part of Minnesota, the lake itself as a whole stands out boldly in its general features, and its effect upon the state of Minnesota is very pronounced and important. It is one of the most marked illus-

* His final and full report is published as Monograph xxv of the United States Geological Survey. This is so well known that no description is called for here.

trations of the action of the ice-margin on the surface drainage in those regions where the natural slope was toward the glacier.

12. Lake Issati

In the same manner that the Saint Croix river was obstructed and caused to form a lake (lake Shafer) above the point of obstruction and to pass round the ice toward the east, so the Mississippi and the Rum rivers, both flowing southward, were obstructed, with similar results. In this case, however, the obstruction was by the northeastern ice-lobe and at an earlier date. Lake Issati was an enlarged lake, which covered the region of lake Mille Lacs. It has not been studied, and it can only be said that it stood at a level of about 1,266 feet above the sea and probably had an outlet through Crow Wing county by way of the Nokasippi river into the Mississippi. The ice-tongue from the northeast lay with its northern edge encroaching on the southern part of the present area of lake Mille Lacs, shutting up the passage southward by way of Rum river and depositing a coarse marginal moraine. When this obstruction was removed the level of lake Issati was lowered to about that of Mille Lacs, amounting to about 12 feet.

13. Lake Aitkin

This lake was named and described by Mr Upham.* It stood at 1,205 feet above the sea and formed distinct beaches and deposited a lacustrine clay. According to Mr Upham's interpretation, the obstruction of the Mississippi river below this lake was due to the northwestern ice-lobe, and the region of Willow river was covered by the northwestern glacier, limiting the lake in that direction. It is more in accord with the manner of retreat of these ice-lobes from the state, as already intimated in the description of lake Shakopee, to suppose that lake Aitkin was due to the Lake Superior ice-lobe, whose northern margin can be traced by a nearly continuous moraine from Crow Wing county to Carlton and Saint Louis counties, thrusting the Mississippi river toward the west and southwest from Sandy lake to the mouth of the Crow Wing river. That would leave a large area toward the north, through which the Willow river flows, and which in its physical features is like the region about Aitkin, subject to overflow by lake Aitkin; hence lake Aitkin is allowed a wide extension toward the north on the accompanying map.

The outlet of this lake must have been toward the southwest around or over the western edge of the obstructing glacier, and it may have

* Final Report of the Geological Survey of Minnesota, vol. iv, p. 46.

caused glacial kames in southern Cass county similar to the Bridgewater kame in Rice county.*

14. Lake Saint Louis

This lake was situated in Carlton county, and was formed by the ponding of the water of Saint Louis river at a date somewhat later than the existence of lake Aitkin. It was described by the writer in the final report of the Minnesota geological survey,† published in 1899. Its outlet was at about 1,135 feet, and passed into the Kettle river and to the Saint Croix. Thus the action of the ice-margin was to divert waters that belonged to the Saint Lawrence River system across the continental divide into the Mississippi system.

15. Lake Nemadji

It required but a slight retreat of the northwestern margin of the Lake Superior ice-lobe to uncover a lower passage tothe Kettle river, and hence to drain lake Saint Louis. This second outlet was also in Carlton county and at a level of 1,070 feet above the sea, or 65 feet lower than the level of lake Saint Louis. The lake here formed covered at length the valley of the Nemadji river, which flows into the western end of lake Superior, and continued long enough to enable it to make perfect records in all those ways by which glacial lakes are recognized. It deposited a thick blanket of lacustrine clay, it had a marked channel cut through the earlier deposited till, and it formed conspicuous beaches.

16. Lake Duluth

This name, which was applied by Mr F. B. Taylor, is synonymous with "Western Superior Glacial lake," a name applied by Mr Upham, and is preferred, notwithstanding Mr Upham's priority, because of its brevity and appropriateness as contrasted with the cumbrousness and the indefiniteness of the title used by Mr Upham. This lake was from 12 to 15 feet lower than lake Nemadji and covered nearly the same area. Its outlet was by way of lake Brulé, in Wisconsin, and thence to Saint Croix river. It became a large lake, and its beach line is very marked, although it has not been well differentiated in this respect from the beach of lake Nemadji. At the present time the level of the outlet at Brulé lake is so nearly the same as that of lake Nemadji, in Carlton county, as to lead one to believe that lake Duluth had the same level as lake Nemadji. It is, however, now a pretty well established principle

* Final Report of the Geological Survey of Minnesota, vol. i, p. 665.
† Op. cit., vol. iv, p. 20, and foot-note.

that since these lakes existed the shore line of lake Superior has suffered a differential elevation, increasing toward the north and east, amounting to about three inches per mile. Making allowance for this change, the distance between the outlets being about 40 miles, the Brulé outlet would be found to have been at least 10 feet lower than the Nemadji outlet. As long as these outlets to the Mississippi basin continued, the Saint Lawrence basin was deprived of a large amount of the surface drainage which now passes over Niagara falls.

17. Lake Nicollet*

It has been stated that the line of contact and confluence of the two great ice-lobes passes northwestwardly from the central part of the state, say Dakota county, and that in the retreat of these lobes the drift of this contact line was left in a state of confusion and overlapping complexity. This can be followed to the vicinity of Itasca lake, where it turns eastwardly. The interlobate area first uncovered was uniformly one of greater elevation than the areas covered by the ice adjoining. On the retreat of these ice-lobes from the vicinity of Itasca lake the included area next eastward naturally sloped eastward, and the interlobate area hence became covered with a glacier lake. This lake was hemmed in by higher land toward the west, partly morainic, and by the two glaciers toward the northeast and the southeast. Here gathered a great Victoria Nyanza, destined later to be the perennial gathering place of the initial waters of the Mississippi. Across this area the line of confluence of the retreating ice-margins is screened by the accumulations of lacustrine sediments. It reappears on the east in the compound moraine which runs eastward from Pokegama falls and Grand Rapids, approximately coinciding with the Mesabi Iron range nearly as far east as Birch lake. The level of this lake was about 1,390 feet above the sea, and its outlet was through the valley occupied by the " chain of lakes," extending from the southwestern arm of Leech lake across Hubbard county to the upper waters of the Crow Wing river. When this lake was drained, Leech lake appeared at a level of about 95 feet lower, Winnibigoshish about 100 feet, and Cass lake about 90 feet. These lakes are connected by a sluggish, winding stream, which continues with about the same characters to near Pokegama falls.

18. Lake Beltrami

Another interlobate lake was farther north, and was apparently more dependent on the northern glacier than on the southern. It had its

* This large lake is named Nicollet from the great geographer of the fifth decade of the century, whose indefatigable labor first represented this upper region of the Mississippi on a suitable chart.

outlet in the valley in which Beltrami found lake Julia, known as the "Julian sources" of the Mississippi, from which, as he stated, the water drains north to Red lake and south to the Mississippi. There are some evidences of the existence of a large interlobate lake in this region a little subsequent to lake Beltrami, whose outlet was westward along the gravelly channel that passes about two miles west of Bagley from Beltrami county into Norman, as represented by Professor Todd, and that may have been the principal way of discharge of lake Beltrami. The connection, however, has not been established. Lake Beltrami is supposed to have lain mainly north of lake Julia, and to have had discharge southward into lake Nicollet. Its elevation was nearly 1,450 feet, or later at about 1,400 feet.

19. Lake Thompson

There is still another abandoned watercourse lying in the southeastern part of Polk county, running in a southwestward direction, parallel with that in Norman county, which probably drained another glacial lake similar to lake Beltrami but larger, and at a somewhat later stage of the northern ice, when the interlobate area due to the elevation of "Beltrami island" had been largely increased. The size of this lake has not been ascertained, and while it is here named from the Canadian astronomer and geographer who first passed through this valley to the Mississippi,* and its elevation can be given approximately as 1,200 feet, its outlines as shown on the map are hypothetical, being drawn from the contour lines of the maps of Professor Todd and a general knowledge of the manner of retreat of the ice-margin. On the farther retreat of the ice-margin Red lake was the residual inheritor of these waters. From this it seems likely that Beltrami island, lying to the north and northwest of Red lake, cooperated with the margins of the two ice-lobes in separating lake Agassiz into two main parts, one being about 75 feet higher than the other and divided from it by a river about 25 miles in length. This higher lake was responsible for the lacustrine features of the country drained by the Bowstring river.

20. Lake Big Fork

This brings us logically to a consideration of Big Fork lake. There is even now sometimes a continuous watercourse between the upper waters of Bowstring river and lake and the Mississippi at Winnibigoshish lake. This connection must have once been quite important and constantly active in turning the upper waters of the Bowstring into the Mississippi.

* Final Report of the Geological Survey of Minnesota, vol. i, p. 109, note.

The limits of the lake there formed are not known. This lake is hypothetically represented on the map. In its lower stages it may have been much enlarged, and its outlet may have been toward the west, into the Red river of the North, through lake Thompson. When it was permanently connected with the Mississippi its elevation was about 13,000 feet, lake Winnibigoshish being now 1,290 feet. If its waters ever passed through the abandoned channel mentioned, in Polk county, its elevation must have been lowered to about 1,225 feet.

21. Lake Upham*

When the northwestern edge of the lake Superior ice-lobe crossed the valley of the Saint Louis river, that river was ponded back and produced, as already explained, two glacial lakes—lakes Saint Louis and Nemadji—and its water was turned to the Mississippi. Those lakes were respectively 1,135 and 1,070 feet above the sea. But prior to those lakes the Lake Superior ice-lobe had thrust its margin still farther northwestward, and had dammed back the Saint Louis at a higher level, forming lake Upham,† at 1,300 feet above the sea, which had its outlet into the Mississippi throngh a channel not well known, but undoubtedly across the low divide which separates the waters of East Savanne river from those of West Savanne river, in the northeastern part of Aitkin county. This passage across the divide was long used by the early fur traders in traveling by canoe from the upper Mississippi to lake Superior. The actual channel has not been discovered, and there are good reasons for locating it near the ice-border, farther south. In case it was along this ice-border the lake must have had an unsteady surface level, and the water probably passed to the Mississippi through the valley of Prairie river. There must have been instances in which the river trenched on the ice, and that may have formed the kame which is known to exist on the portage line from the Saint Louis river to Prairie lake‡ in township 50, range 20.

Lake Upham was a large body of water, and extended from near the Mississippi, in Itasca county, to beyond the center of Saint Louis county. The region which it covered is still poorly drained, and is covered largely by an extensive peat bog. In general, it occupies the triangular area between the gabbro highlands on the south, on which the southern moraine is piled, and the Giants range of granite on the north, on which

* This lake was named from Mr Warren Upham, whose assiduity and long labor brought to light most of the features of the drift of Minnesota.

† This lake was briefly described and named in vol. vi of the Final Report of the Geological Survey of Minnesota, Atlas, plate 66.

‡ This very significant kame was noted in the Ninth Annual Report of the Minnesota Geological Survey, p. 110.

the northern moraine is piled. On the west it was confined by an earlier moraine which separated it from the Mississippi river.

22. Lake Norwood

In the retreat of the margin of the northern ice-lobe four glacial lakes were formed on the north side of the Giants range, of which the earliest has been named from Dr J. C. Norwood, who first as a geologist passed through some part of its area and left a description of some of its features. This lake was located in Saint Louis county, and was about 25 miles long, from east to west. Its outlet was through the Mesabi moraine, toward the south, into lake Upham, and thence to the Mississippi. Thus again, in the later stages of the Wisconsin epoch, were waters belonging to the Hudson Bay drainage system turned into the Mississippi basin. This lake covered the valley of the Embarrus river north of the Mesabi iron range and extended westward so as to include much of that of Pike river. Its date was before the formation of the Vermilion moraine, and its elevation was about 1,450 feet above the sea.

23. Lake Dunka

Eastward from lake Norwood the valley which is now occupied by Birch lake, naturally having an outlet northward, was obstructed by the ice-margin in its recession from the Vermilion moraine, and a lake was formed which had an outlet westwardly along the north side of the Giants range into the valley of lake Norwood and thence to the Saint Louis and the Mississippi valleys. This lake stood at a level of about 1,495 feet. Its terraced gravels are quite conspicuous about the southern shores of Birch lake. It was apparently not a large lake, and it had a rapid river-like connection with lake Norwood until it was drained northward.

24. Lake Elftman

Mr A. H. Elftman has named "Gabbro" lake, but as that is the name of the present lake which occupies a part of the same area, it is likely to cause some confusion, and it is proposed to give Mr Elftman's name to this lake, he having first described it. It occupied an area still farther east than Dunka lake and covered a tract in which there is but little drift, now drained by Kawishiwi river. Its outlet was southward and then westward and into the southeastern corner of lake Dunka by way of Stony river. It had an area of about 100 square miles at the time of its greatest extent and an elevation of about 1,700 feet above the sea. On

the north its barrier was the northern glacier, and on all other sides it was shut in by high gabbro hills. Its shoreline must have been very tortuous. Its surface lay higher than that of any known glacial lake in northern Minnesota, and its waters probably reached the Mississippi river through lake Upham and Sandy lake, in Aitkin county.

25. Lake Onnamani

This is the Indian name of the present Vermilion lake, and this lake covered the same area and rose about 10 or 15 feet higher, its outlet being about 1,370 feet above mean tide. The southern margin of the northern ice-lobe at that time crossed the northern confines of Vermilion lake, closing the present outlet. Lake Onnamani had discharge westward from Partridge lake (the most northern portion of Vermilion lake) through Hoodoo lake to Elbow and Pelican lakes, and probably ultimately into the extreme eastern part of lake Agassiz or lake Thompson.

There were other glacial lakes due to the northward barrier of the northern ice, but it is not necessary to dwell on this feature to much greater length. One is known to have covered the valley occupied now by Long and Fall lakes, and it is probable that the waters of Vermilion river were constantly ponded back, so as to find outlet over a low divide into a branch of the Little Fork river.

26. Lake Omimi

There remains only lake Omimi, which was the latest of the glacial lakes to disappear from the territory of the state. This was described and named by Mr A. H. Elftman* in 1898. It occupied the valley of the Pigeon river at and above the western landing of the "grand portage" trail. It covered about 40 square miles, with an outlet about 1,360 feet above the sea. A stratified clay formed by this lake is seen along the Pigeon river and along its tributaries from the west. Mr Elftman considered that the outlet of this lake, which has not yet been discovered, was toward the southeast; but it is difficult to accept that supposition, since the ice-barrier itself which caused this lake lay along the southeast. The outlet was more probably toward the southwest and to the Brulé river.

Other Lakes

Besides the lakes which have been mentioned, there were several in the southwestern part of the state, along the Coteau des Prairie which,

*American Geologist, vol. xxi, p. 104.

though small, served to produce a remarkable topography, which has been described by Mr Upham. Lakes Benton, Shaokatan, and Hendricks, the last within the territory of South Dakota, were embraced in the interval between two glacial moraines, and were at one time much extended. On account of the ice-barrier toward the northeast, these valleys were filled by glacial lakes whose outlets were across the outer moraine. Here were excavated conspicuous channels,* which remain to this day and testify to the power of the streams that formerly passed through them. These lakes were each about 1,850 feet above the sea.

Similarly, lakes Shetek and Heron, farther southeast, were once much enlarged by the obstruction caused by the ice-margin in its retreat northward. Lake Shetek probably extended for at least 10 miles up the Beaver Creek valley and covered the Des Moines valley southeastwardly to the Great bend of the Des Moines. Lake Heron, a little farther southeast, was blocked in its northern outlet to the Des Moines by the glacier that formed the moraine at Windom. It rose sufficiently to cross the divide toward the south, and took the old abandoned channel southward through Jackson county.

Glacial Lakes of the Driftless Area

There remains yet to be mentioned another interesting class of glacial lakes. These were located in the deep gorges of the Mississippi valley, within the "driftless area" of the state. In order that it may appear in what way these lakes can be included in the category of glacial lakes, it will be well to recall some of the facts which have been ascertained respecting the glacial epoch in Minnesota, so far as it relates to the Mississippi gorge at and below Hastings.

It is now several years since the writer noted occasional deposits of till, and sometimes northern boulders in the gorge of the Mississippi, well within the "driftless area," when such could not be found in the country farther west. This was observed at Winona and at Red Wing. At the same places, and indeed all along the Mississippi, both within and outside of the "driftless area," the river is bordered by terraces of gravel and sand which are like those of the rivers in drifted regions, the material of which is freely attributed to the wash of the drift brought forward by the glacier. Toward the north, indeed, these gravelly terraces merge into those which are connected with the morainic belts and with the gravel plains of the upland. It has been difficult to understand how such gravel and sand could be so far transported by a gently flowing current from its supposed source.

* Final Report of the Geological Survey of Minnesota, vol. ii, pp. 603, 604.

It should be noted again that the western border of the lake Superior ice-lobe, in the latitude of Saint Paul, crossed the Mississippi valley at Saint Paul, deployed on the northern part of Dakota county, but barely appears as such in Goodhue county, and is not traceable in Wabasha nor any of the valley counties farther southeast. If it ever existed in those counties it has been buried by later modified drift, and it never filled the valleys with till. But southward from Saint Paul, and especially southward from Hastings, and also still more remarkably along the Saint Croix valley northward from Hastings, gravel and sand terraces are very abundant.

In order to explain these features, and also to account for the great depth and width of the gorge of the Mississippi, it may be supposed that a long tongue of ice was continued southward in the Mississippi gorge from the main ice-margin, and that for a long time it subsisted after the average limit of the ice had retreated farther north. This tongue of ice could be compared to those that occupied the valleys of the finger lakes of New York or the Cuyahoga valley in Ohio, or to the long slender glaciers which still in northern latitudes fill the fiords which reach the sea. The inevitable consequence of such a glacier in the Mississippi gorge was to pond back the tributary streams until they were raised high enough to flow over the ice or along its margin. Such ponding formed the lakes here called glacial lakes.

It may be added, further, that this would have been the result for each of the glacial epochs that have been identified in Minnesota, and that the drift deposits of the different advances of the ice would be mingled with those of the retreats in confused order, and that the drift of the separate epochs would overlap. Such features have been observed. There are older and later gravel terraces, and each has its relation to the flooded stages of the rivers, probably due to such cause.

What agency such occupancy of the gorge of the Mississippi by a narrow glacier fed by the ice-fields farther north may have had in the production of the greater lake which is sometimes supposed to have covered the "driftless area," and hence of the loam which is spread everywhere in that area, it might be interesting to inquire. Owing to the nature of the supposed obstruction, such a lake could rarely, if ever, form a continuous beach line. It must have mixed its beach deposits with the earlier till, or with the earlier loam, all about its edge. It must have retreated slowly, and its effects as a lake would have been most marked in the northern portion of its extension; and finally it would have become broken up and shrunken to the limits of the tributary gorges, and thus would be at last wholly drained to the Mississippi as the ice-tongue in recession opened one after the other of those valleys.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 12, PP. 129-146 MARCH 25, 1901

MARINE AND FRESHWATER BEACHES OF ONTARIO

BY A. P. COLEMAN

(Read before the Society December 28, 1900)

CONTENTS

MARINE DEPOSITS

The Pleistocene marine beds of Ontario have been studied for many years and have yielded a great number of fossils at different points along the Saint Lawrence and Ottawa and in the country between these two rivers, as well as along the rivers flowing north into Hudson bay,* proving that the sea once occupied these regions for a length of time sufficient to form beds of clay and sand often more than 100 feet thick. Sir William Dawson has divided these deposits into "Leda clay" and "Saxicava sand," the names being derived from the commonest fossils occurring in them. The Leda clay usually rests on boulder-clay, and the Saxicava sand usually overlies the Leda clay, so that in general one may say that the stratified marine beds were formed later than the last retreat of the ice from the region mentioned.

Probably the beds most productive in fossils of any of these deposits in Ontario are those in and about Ottawa, and these may be described as typical. The Leda clay is well disclosed in the city itself, and at Greens

*Geol. Can., 1863, pp. 915-928; Can. Ice Age, Sir Wm. Dawson, pp. 203, etcetera; Reports of Dr Bell in the Geol. Survey Can., 1871-'72, p. 112; also 1875-'76, p. 340. Dr Ami also has collected many species, some of which are enumerated in the Ottawa Naturalist, vol. xi. no. 1, pp. 20-26.

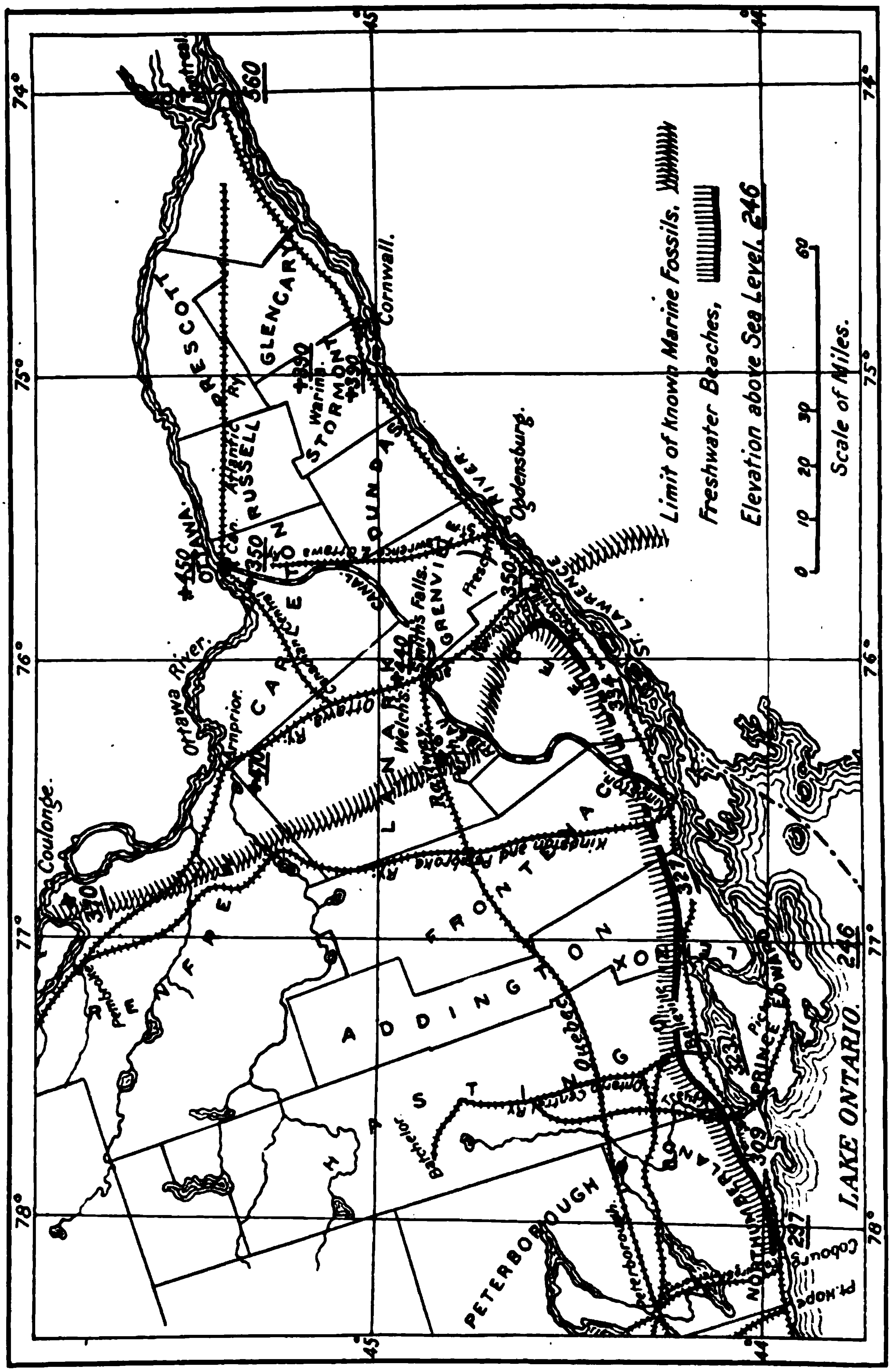


FIGURE 1.—Map of eastern Ontario, showing limit of freshwater Beaches and of marine Fossils

creek and Besserers wharf a few miles down the river. The clay, which is bluish gray and well stratified. rises about 40 feet above the Ottawa, or about 160 feet above the sea, and contains in many places great numbers of concretions, well known for the beautifully preserved fossil fish they often enclose. In addition to the capelin (*Mallotus villosus*) and two or three other fish, *Leda arctica*, *Saxicava rugosa*, and *Macoma fragilis*, with some other species of shellfish, have been found in the concretions. From brickyards in the city a number of other fossils—shellfish, a sponge, foraminifers, etcetera—have been obtained.

In addition to the marine forms mentioned, a large number of land and freshwater plants and several birds and mammals, including a seal and a chipmunk, have been obtained from the concretions, showing that the Leda clay was formed not far from a shore where clay, with drift materials, was brought down by rivers. Although Leda itself may occur in moderately deep water, most of the other fossils suggest shallow water.

In Nepean township, 6 miles up the Rideau river from Ottawa, the Leda clay rises to about 310 feet above sealevel, but here no concretions are found, and the number of species of shellfish is small. Leda clay with concretions is found 60 miles northwest of Ottawa city, on lake Coulonge, an expansion of Ottawa river, at a height of 370 feet above the sea, according to Doctor Ells,* and at many points down the river and along the Saint Lawrence. Very similar stratified clays occur at levels above this, even up to 1,000 feet, but marine fossils have not been reported in them above 370 feet. The fossiliferous clays near Ottawa are stated to be 140 or more feet in thickness, and as they are very widely spread, their deposit must have demanded a long time. The Leda clay of Montreal and points farther east and northeast along the Saint Lawrence, which will not be referred to here, has been well described by Sir William Dawson in "Canadian Ice Age."

The Saxicava sands cover a greater area than the clays, but contain fewer species of fossils, the usual ones being *Saxicava rugosa* and *Macoma fragilis*, whose white, but well preserved, shells could sometimes be collected by bushels. A good exposure of these sands occurs at the point 6 six miles from Ottawa, on the Rideau river mentioned before, where overlying the clay there are about 40 feet of sand, showing more or less cross-bedding and evidently deposited in shallow water.

Beside the two ubiquitous shellfish mentioned above, many shells of *Mytilus edulis* occur, often beautifully preserved with the two valves still united; and one finds also a few balani. The shells are most numerous just where the sand and clay join, but are found more or less frequently

*Sands and Clays of the Ottawa Basin, Bull. Geol. Soc. Am., vol. 9, pp. 215 and 216.

all the way up. The sand rests conformably on the clay, and rises to a level of about 350 feet above the sea. The surface of the adjoining country is sandy, with a somewhat rolling and duny character, but without any well marked shoreline; so that the sand was probably laid down as shoals in shallow water.

Similar sands with shells are reported by Doctor Ells at higher points farther up the Ottawa—that is, at 470 feet along the summit of rocky ridges to the west of Arnprior.

The sands occur widely spread also in the flat country south of Ottawa, good instances being seen along the Nation river and its tributaries near the villages of Avonmore and Monklands, where drainage operations give good opportunities to study them. Here one finds broad, swampy tracts more or less covered with peat, beneath which is a layer of sand from 2 to 5 feet thick, crowded with shells of saxicava and macoma and resting directly on bluish boulder-clay with no stratified clay intervening. In some places a layer of sand, containing many small freshwater shells of at least eleven species, rests on the marine sand with no apparent break between the two, so that the same spadefull contains both, though there must have been a considerable lapse of time between the formation of the two layers of sand. At some points on the drainage ditch the boulder-clay is missing, and the marine sand, with shells, rests directly on the flat limestone of the region, the boulder-clay having been removed perhaps by erosion. These sand beds are from 320 to 330 feet above sealevel.

The association of freshwater with marine shells in different beds of the same section is, of course, not a new thing, since Sir William Dawson long ago mentioned similar relationships in stratified clay and sand at Pakenham, northwest of Ottawa.*

Shell-bearing Gravels

Still more frequent than shell-bearing sands are banks and ridges of gravel containing the same fossils—Saxicava gravels, as they may be called—which often have a substratum of boulder-clay, and in many cases consist of morainic or kame-like deposits, probably of glacial origin, rearranged by wave action. Many of these ridges are found in the neighborhood of the villages of Finch and Avonmore, and they are often elongated in a direction of about north 15 degrees or 20 degrees east, which corresponds to the general direction of the glacial striæ of the region. They are not eskers, however, being too short and consisting often of a ridge

* Can. Ice Age, p. 58.

of boulder clay, with a few feet of coarse, shelly gravel resting on or against it. It appears as if these ridges formed shoals in the shallow sea, where wave action worked up the stones of the boulder-clay into local gravel deposits, one thin sheet of shelly gravel even lying on top of a drumlin of rather irregular shape west of Finch.

A typical example is found at McMillans gravel pit near the same village, where 12 feet of gravel, with *Saxicava rugosa*, *Macoma fragilis*, and *Mytilus edulis*, rest on 10 feet of very stony boulder-clay, the whole sloping off gently on all sides to the level plain.

One of the largest of these gravel deposits occurs north of Monklands, at a railway ballast pit called Warina, where a steam shovel is at work, exposing a fresh section 30 feet high, showing coarsely stratified gravel and sand, in the lower part containing many boulders, sometimes 3 or 4 feet in diameter. The lower portion of the deposit, which rests on stony clay, shows no shells, but the upper and better stratified gravel and sand look like a beach formation, having thin layers of garnet sand and many shells of saxicava and macoma. This gravel hill runs about north 35 degrees east and rises 390 feet above sealevel.

Many other ridges of the sort, some as large as the one just noted, but most of them smaller and lower, are to be seen in the region; but only the most southerly, near Newington, need be mentioned. The general arrangement here is the same as at Warina, but the hill, which rises to 390 feet also, trends east and west and slopes off gently toward the south, changing in that direction into evenly stratified sand with shells—saxicava sand.

The most westerly of these gravel hills, at Welchs, north of Smiths falls, is famous for the bones of a whale found there in 1882, in a railway ballast pit, at a height of 440 feet above sea. At present little is to be seen at the pit, which has been disused for a number of years. The gravel, which is often bouldery, shows a face of 52 feet, but no shells are to be found in it, and the whole deposit, which is an irregular kame-like ridge, having a shallow kettle hole on top and running north 15 degrees east, like the striæ on the Potsdam sandstone beneath, suggests ice action rather than wave action. Mr Taylor is probably correct in supposing that the bones, which are of *Megaptera longimana*, a whale now common in the gulf of Saint Lawrence, were deposited in a beach cut on one side of the ridge and not in the ridge itself.

The shell-bearing gravels along the river Saint Lawrence appear to end a little west of Prescott, at the Gladstone gravel pit, opened on a kame consisting often of very coarse materials. There are no shells in the body of the deposit, only in some small patches of silt and gravel

resting unconformably on the surface of the kame, about 320 feet above the sea, and the only shell observed is *Macoma fragilis* of unusually large size. A few fragments of the same shell were seen in a gravel ridge rising about 350 feet (aneroid) above sealevel on the south side of the Grand Trunk railway, a mile and a half west of the last point. The bed of gravel is 10 feet thick, rests on a floor of blue clay, probably till, and consists of rather fine, well rounded materials distinctly stratified and sometimes cross-bedded, having all the look of a beach ridge. Not far off to the north of the railway there are rock cliffs which appear to have been cut by wave action.

While no marine shells are to be found west of this at present, Doctor Robert Bell obtained some many years ago at Brockville, 7 miles farther in that direction, in clays penetrated by a tunnel under the town. This is the most inland point at which marine fossils of any kind have been reported.

Doctor Gilbert states that clays and sands rich in shells like those described above are common in the state of New York, south of the Saint Lawrence, but on that side also they appear to cease before reaching Morristown, opposite Brockville.

Gravels, sands, and clays not unlike the marine deposits which have been described occur at various places west of Brockville—for example, at Lyn, Gananoque, and along the bay of Quinte—and some of them have been searched carefully for fossils, but without success, suggesting that for some cause the marine fauna could not advance into the Ontario basin.

Old Water-levels to the West

While the marine fossils disappear there are evidences of an old water-level corresponding to the beach ridge found between Maitland and Gladstone, extending on to the west. At Lyn, a few miles beyond Brockville, rocky hills rise a little way from the river, but at their foot are level clay flats at an elevation of 325 feet above the sea, corresponding fairly well with the beach gravels at 350, since a beach ridge always stands higher than the clays and silts laid down in enclosed waters.

Similar clay flats are found at Mallorytown, 8 miles farther west, and at Lansdowne. From this point to Ernestown, 35 miles farther, traces of this water-level have not certainly been found, but beyond this it may be seen from point to point, and at Belleville a boulder pavement at 323 feet above the sea probably represents it. Near Brighton the lowest water-level, which is well marked and has a shore cliff of boulder-clay rising 60 or 70 feet above it to the north, stands at 309 feet; and what

seems to be a continuation of the same shore has been traced as far as Cobourg, where it is at 297 feet above the sea. Beyond this it has not been followed, though a vague water-level near Toronto, rising 20 or 30 feet above lake Ontario, which is 246 feet above sealevel, may be a continuation of it.

Beach lines equivalent to the one mentioned have not yet been reported from New York state, though they should be found there if there were wave action sufficient to form them on the Canadian side. Doctor Gilbert describes a well marked terrace on a hill to the east of the region mentioned, but apparently too far above 350 feet to be a probable continuation of the water-plane traced west of Brockville.

If we suppose the somewhat faintly marked old shore described above to be the continuation of the marine beaches to the east of Brockville, the northeastern part of the region must have been considerably deformed since the Saxicava sands and gravels were laid down, for the finding of bones of a whale at 440 feet at Smiths falls, of shelly sands near Ottawa and Arnprior at 470 feet, and of beaches with shells at 560 feet at Montreal indicates a somewhat rapid rise. Between Maitland and Montreal the average rate of differential elevation is 1.75 feet per mile; and if we take the beach at 615 feet, in which, however, no shells have been found,* it will amount to about two feet per mile. If we compare Welchs, near Smiths falls, at 440 feet, with Ernestown, 60 miles to the southwest, at 327, the rate is a little under two feet per mile. These are not improbable rates of differential elevation when compared with those worked out for the Iroquois beach to the west, but the variation in level between Maitland and Welchs, 30 miles to the northwest in a line nearly at right angles to the supposed direction of greatest deformation, is 90 feet, or 3 feet to the mile, which seems hard to account for.

It is possible that in the beginning the sea stood for a short time higher than the main beach levels indicate, forming then the deposits at Welchs and the water-line noticed by Doctor Gilbert in New York. The vague character of the beach at Welchs suggests only a short time for wave action. In connection with this it may be mentioned that fairly distinct beaches have been found by myself at various higher levels in the Bay of Quinte region of lake Ontario, on the bay shore of Prince Edward county at 378 feet, northwest of Belleville at 416 feet, and near Trenton at 390 feet; but thus far these fragmentary beaches have not been traced for any distance, and could be correlated only doubtfully with beach levels farther east. If these beaches were of marine formation, the sea probably occupied the region for too short a

* Can. Ice Age, p. 63.

time to leave much impress, and as no fossils occur in them the solution of the problem must remain doubtful.

That the old sealevel at 350 feet continued into the Ontario basin, and may even have reached its western end, seems very probable, and the fact that marine fossils are very abundant east of Brockville, but have never been found to the west, may be accounted for by the narrowing of the lower end of the basin forming a strait not very much wider than the present river and only 100 feet deeper; so that Niagara and the other rivers flowing into lake Ontario were able to keep the waters fresh, or at least only brackish, in spite of their communication with the enlarged gulf of Saint Lawrence.

It may fairly be asked if the beach-like deposits of sand and gravel and also the stratified clays resembling the Leda clay occurring at higher levels in the region west of the fossiliferous beds may not also be of a marine origin, and geologists who have begun their studies in the maritime provinces, where many elevated sea beaches exist, are inclined to this view. Sir William Dawson, Doctor Ells, and Mr Chalmers have looked on these higher stratified deposits, even up to 1,000 feet to the east of Toronto, as probably marine; * and Doctor Spencer has described the Iroquois beach, rising at Brighton and Trenton 275 or 300 feet above the beach levels referred to in this paper, as formed in an arm of the sea. This conclusion is a very natural one and tends toward simplicity by avoiding the assumption of an ice-dam; but the finding of freshwater shells in the Iroquois beach near Toronto seems conclusive as to the character of the water, which could hardly remain fresh or even brackish with an opening 70 or 80 miles wide and 400 feet deep into the inland sea formed by the enlarged gulf of Saint Lawrence.

If the Iroquois beach is of freshwater origin, there is no need to prove that the higher beach-like deposits are not marine. It may be that some of them were not even formed in standing water, but are glacial and of a kame-like nature, though this can not be stated positively without some field work in the region. As seen from the Canadian Pacific railway, the latter view seems probable in at least a few cases.

Climate, and Age of the marine Beds

The fossiliferous beds of the Ottawa and Saint Lawrence valleys are sometimes spoken of as interglacial, though they can not be considered interglacial in the same sense as the Toronto formation or other fossiliferous deposits lying between two sheets of till. They usually rest on

* Bull. Geol. Soc. Am., vol. 9, p. 214; Geol. Survey Can., vol. x, 1897, pp. 68 and 69 A.

boulder-clay or a striated rock surface, or form the upper beds of kame-like hills, but have not yet been shown to be covered by boulder-clay or any other well marked glacial materials. It is true that scattered boulders, which may be called erratics, sometimes rest on them, but these have probably been transported by floating ice when the sea stood at its higher level, just as river ice transports large boulders in the Saint Lawrence at the present day.

As to the temperature of the time, the plants found in the Leda clay nodules at Ottawa, 28 species in all, as determined by Professor Penhallow, are all represented in the same region at present, and include the sugar maple, the yellow birch, and the common and balsam poplar, trees of a cool temperate but by no means arctic climate. Of the other fossils much the same may be said. The chipmunk is common in the same region now, the feathers and bone of a bird have not been determined, and the four species of insects—*Fornax ledensis*, *Tenebrio calculensis*, *Byrrhus ottawaensis*, and *Phryganea ejecta*—as determined by Doctor Scudder, are extinct and do not add much to our data. The seals, dolphins, and whales found in our deposits are all still living in the gulf of Saint Lawrence, and the same is true of most of the 26 other marine animals recorded.* The Arctic species mentioned by Sir William Dawson are apparently still living in the Gulf and do not indicate a climate greatly different from the present, though perhaps somewhat colder, so that these beds are not interglacial even in the sense of having been formed while glacial ice occupied the shores of the inland sea, though it is possible that the Labradorian ice-sheet had not wholly vanished at the time they were being formed.

If the usually accepted theory that the Iroquois water was dammed by glacial means is correct, the marine beds of the Ottawa-Saint Lawrence region could not have been formed until the ice-tongue, hundreds or thousands of feet thick, which obstructed the lower end of the Ontario basin, had melted away, and this provides some data for estimating their age. If we suppose the formation of the Iroquois beach to have taken half the time since Niagara began its work, and this is not an unreasonable supposition, there is available for all subsequent events a time variously estimated at from 2,500 to 16,000 years. Within this time the great ice-dam must have melted, implying a retreat of the glacial front for at least 100 miles, and widespread sheets of sand and laminated clay, sometimes more than 140 feet thick, were laid down, and afterwards eroded to the depth of at least 110 feet by the Rideau and other rivers.

* Can. Ice Age; also contributions to the paleontology of the post-Pliocene of the Ottawa valley, Dr Ami, Ottawa Naturalist, vol. xi, no. 1, pp. 20–26.

Since the marine beds were formed sufficient time has elapsed to allow the region of Ottawa to rise 470 feet, and that of Montreal 560 or perhaps 615 feet, and within the same time limits apparently 6 species of animals have become extinct—4 insects, an ostracode (*Estheria dawsoni*), and a sponge (*Craniella logani*, Daws.).

In addition to the considerations just mentioned, the present beach of lake Ontario, with its fairly mature forms, including the cutting of cliffs hundreds of feet high and the building of gravel bars miles in length, as at Scarboro and Toronto, must have been worked out since the barrier at the Thousand islands came into existence, and therefore since the completion of the marine deposits just to the east, for they rise a hundred feet above it.

Though we do not know the exact rate of any of these operations, all of them seem to demand a large amount of time, and the lower limit, of 2,500 years, let us say since the time of Pericles or the founding of Rome, seems quite inadequate, and even the upper one, of 16,000 years, not too great.

High-level Beaches in southern Ontario

Two or three hundred feet above the most westerly deposits containing marine fossils is the splendidly developed Iroquois beach, followed by the Nipissing, Algonquin, and Warren shorelines, all very distinct and fairly well known through the labors of Spencer, Gilbert, Taylor, and others. These need not be discussed here, except to mention that a few freshwater shells have been found in the Iroquois beach, and that great numbers of freshwater fossils are found in an extensive area near Georgian bay, probably belonging to lake Algonquin, though possibly to lake Warren, showing that at least two of these higher beaches are not marine.

There are, however, beach deposits at higher levels than any of the old shorelines mentioned, the highest of which, so far as recorded, reaches 1,230 feet above the sea.* On the highlands of the peninsula between lake Huron and Georgian bay Doctor Spencer has found several fragments of beaches, around what must have been an old island, at levels from 1,400 to 1,690 feet,† and similar beaches have been described by the present writer at points 1,422 to 1521 feet above the sea in the same district.‡ Some of these are well marked water-levels, with broad terraces

* Mr Taylor mentions water-levels at 1,200 to 1,230 feet near Trout creek, Cartier, etcetera, probably belonging to the Algonquin shores. Am. Geol., vol. xiv, 1894, p. 285. He describes also beaches at 1,530 or 1,540 feet west of Port Arthur, belonging, however, to a relatively small ice-dammed lake which he has named lake Kaministiquia.

† History of the Great Lakes, p. 78.

‡ Bur. Mines Ont., 1900, pp. 176, 177.

and rock cliffs in the rear, and can hardly be accounted for as belonging to the extraordinary river valley described by Mr Taylor farther south on the same escarpment, where only one-half of the channel of the river is left, its eastern side, which was of ice, having melted away. As examples may be mentioned a terrace at 1,521 feet on the Blue mountains near Collingwood, where a terrace large enough to contain several fields lies immediately below a sharp limestone cliff, and terraces at 1,420 feet, with rock cliffs in the rear, south of Meaford, on the same escarpment, showing plainly on both sides of a deep valley which cuts for a mile or two into the tableland. In the latter case, especially, it is hard to see how anything else than static water could have done the work. The same is true of the broad Proton plains which lie almost on top of the old island referred to, at an elevation of 1,630 feet, according to Doctor Spencer,* and consist of clays apparently waterlaid.

If the evidence just given be accepted, the waters by which the terraces were made may have belonged to a higher lake Whittlesey before the latter drained past Chicago.

Beaches farther North

Within the last two years beaches have been found at similar elevations to the north of the Great lakes also. One is found about 30 miles northwest of Michipicoten harbor, lake Superior, on the mountain portage between the waters of White river and Dog river. It is a very distinct terrace, of coarse but well rounded gravel and stones, 1,445 feet above the sea, and has been shown by Professor Willmott to occur again 4 miles to the north, on Pokay lake, at about the same level. On Obatonga lake, at the south end of the portage, there is a well marked and extensive sand terrace at 1,380 feet, and one or two lower ones occur near by, on the same chain of lake expansions, forming the upper part of Dog river, all of them being well above the nearest pass to Hudson bay, which is at Missanaibi, 70 miles to the east, and is 1,115 feet above the sea. It is possible that these terraces were formed in the body of water which made the highest beach on Keweenaw point, 150 miles to the southwest, now about 1,200 feet above the sea, the difference being accounted for by the greater amount of elevation toward the northeast.

If these terraces were of marine origin the arm of the sea which produced them must have been many miles broad and hundreds of feet

*The railway level for Proton is 1,582, and the track has about the level of the plain, which seems to make the elevation 50 feet less than that mentioned.

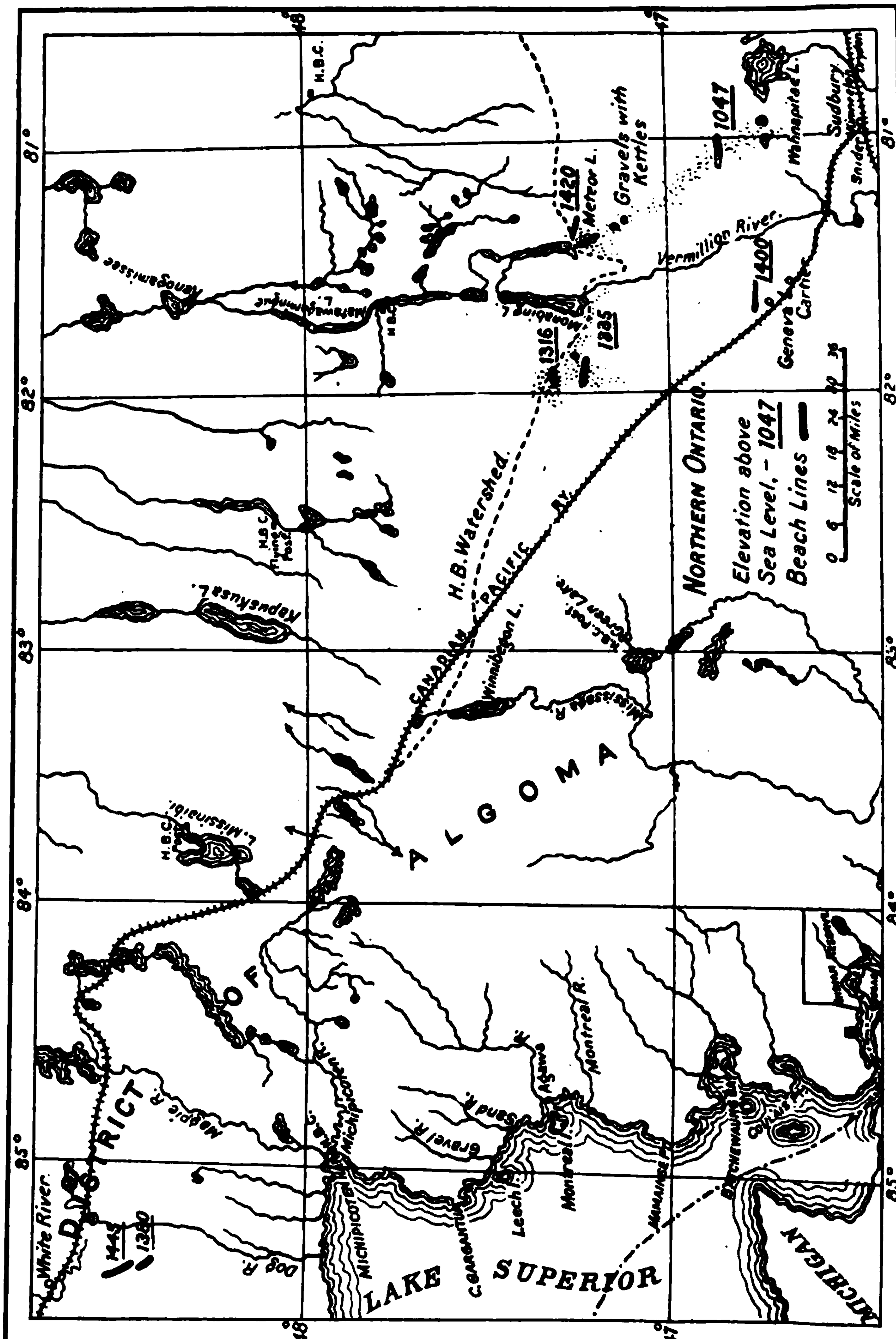


FIGURE 2.—Map of northern Ontario, showing Beach Lines

deep, and must have had connections both north toward an immensely enlarged Hudson bay and east toward the Atlantic. The rugged and mountainous Michipicoten region, which includes the highest known point of Ontario, 2,120 feet above the present sealevel, must have formed a large island.

The other high-level beaches are 200 miles to the southeast of the ones just described, on the watershed between the Saint Lawrence and Hudson bay waters, near Meteor lake, 40 miles northeast of Straight Lake station, on the Canadian Pacific railway, and reachable only by canoes. The region consists mainly of wide sand and gravel plains having an elevation of 1,400 to 1,420 feet, with kames and also esker ridges rising 50 to 100 feet higher. The plains are often interrupted by kettles occupied by lakes, one of the largest being Meteor lake itself, which is 4 miles long. All these lakes have steep gravel banks, evidently not formed by their own feeble waves, but due no doubt to the burying of masses of ice in sand and gravel near the edge of a retreating ice-sheet. The melting of the buried ice gave rise to the cavities now filled by the lakes, some of the smaller ones with no visible outlet.

Meteor lake, as determined by aneroid, stands 1,393 feet above the sea and is reported to be 150 feet deep. It has the not unusual feature of draining both ways—to the southeast by a small stream into Wahnapitae river, which eventually reaches Georgian bay, and to the north by seepage through an esker ridge into Seven Mile lake, which belongs to the Matagami chain of waters emptying into Hudson bay. This is proved by the fact that a narrow bay of the latter lake, approaching within 400 feet of Meteor lake, but at a level 35 feet lower, has clear water, like the lakes in the gravel plain, while the rest of Seven Mile lake has the usual brown water of muskeg regions.

That the sand and gravel of these lakes on the watershed are often well stratified and without the tumultuous arrangement found in kames has been proved by numerous test-pits sunk for prospecting purposes. Polished or striated stones have not been found in them, although the gravel and stones were carefully examined to determine their origin, a matter of interest, since the beds are more or less gold-bearing and have been taken up as placer claims. In some cases also there are terraces which must have been formed by water, as at the Onaping Gold Mining Company's sluices, where one has been cut in the side of an esker and covered with stratified yellow sand quite different from the bouldery gravel on which it is deposited.

The plains were probably formed of materials brought by subglacial streams and dropped at the margin of the ice, but whether in local lakes

or a single large one can not be decided with the information now at hand. It should be mentioned that a sand terrace on the shore of Geneva lake, 45 miles south, has an elevation of about 1,400 feet, and that gravel plains, with kettle holes, at a height of 1,335 feet occur 20 miles to the west, on the divide between the waters of Spanish river, flowing into Georgian bay, and Matagami river.

The extensive gravel and sand deposits just referred to as occupying the watershed between Hudson bay and the Saint Lawrence system of waters were evidently formed at the ice margin during a long halt of the retreating glacier, and the low passes to the north and northeast were no doubt filled by the ice, preventing any connection with Hudson bay, whether the region stood at that time at sealevel or not. If they were formed by salt water it must have been an extension of the gulf of Saint Lawrence; but it is probable that the much lower ground eastward toward lakes Temagami and Temiscaming, the latter only 581 feet above the sea, was still covered with a great lobe of ice, since in the lower parts the ice-mass must have been correspondingly thick, and hence slower in melting. This ice-lobe may even have extended down the lowlands near the Ottawa to the Saint Lawrence, and so have provided the supposed ice-dam of lakes Algonquin and Iroquois, in which case the Algonquin beach must be imagined as extended as far as Meteor lake, with a rather rapid differential elevation of 200 feet between Cartier and Meteor lake, 40 miles to the north.

The source of the immense beds of sand and gravel must have been glacial, since the rocky hills rising through the plains could not have afforded any large part of the materials, being entirely Laurentian, while much of the gravel is of Huronian rock. It appears as if the gravel must have been transported largely against the slope of the country, which falls away toward Hudson bay on the north and toward Temiscaming on the east. The glacial striæ seen in the region run from south to 25 degrees west of south. It is perhaps possible that subglacial streams may transport materials, even coarse gravel, up grade by means of the hydraulic pressure of the column of water derived from the high level of the ice-surface in the rear, much as hydraulic elevators lift gravel in the western placer mines.

Southeast of Meteor lake a succession of similar sand and gravel plains stretches, with a few interruptions, for 40 miles, following in a general way the lake system of Vermilion river, though the headwaters of Montreal and Wahnapitae rivers also start from the neighborhood of Meteor lake. As one advances southeast the level gradually sinks by a series of steps until near lake Wahnapitae similar plains with lake-filled ket-

tles are only 1,000 feet above the sea, though some terraces rise to 1,135. The prospectors of the region, who have taken up almost the whole length as placer claims, think the gravels belong to an old river much larger than the Vermilion; but there is little except the general downward slope of the gravel plains to support this view. The gravels do not follow a single valley, but sometimes occupy two parallel valleys, with a total width of two or three miles, and sometimes cease altogether for a short distance. All the way down there are occasional terraces such as might be formed by wave action.

The fact that this stretch of 40 miles is everywhere auriferous, while sand and gravel areas of a similar kind to the south and west contain little or no gold, suggests a common source of the materials between Meteor lake and lake Wahnapitae; but the gold is generally exceedingly fine, the largest color seen by myself having a value of only four cents, and the scales are much rounded and flattened. suggesting that it may have been transported from a considerable distance, very likely by glacial means.

Conclusions

From the examples cited in the foregoing paper it will be seen that beach lines and terraces more or less well defined occur in Ontario at all levels from one or two hundred to fifteen or sixteen hundred feet above the sea, those of medium height being, as perhaps might be expected, more distinct and continuous than the lower and higher ones, since the opportunities for impressing themselves on the topography were greater. Through various circumstances, due probably to the rate of retreat of the ice and of the differential elevation of the region, some of the water-levels lasted much longer than others, good examples of the more permanent ones being afforded by the Iroquois, Nipissing, Algonquin, and Warren beaches. As a general rule, the higher beach lines are older than the lower ones, though there may be exceptions to this, as in the case of the Nipissing beach as compared with the Iroquois, the latter, though the lower, being the older of the two. This general succession in age from higher to lower may be accounted for largely by the theory of ice-dams, since the last ice-sheet retreated on the whole in a northeasterly direction, the various bodies of water following up its front and leaving the successive beach lines each more greatly tilted than the next one below, if we project their planes to the same vertical line at the northeast of the region. The Nipissing beach, however, not having been formed in an ice-dammed body of water, will to that extent be an exception.

The processes of ice retreat and differential elevation must not be thought of as uniform in rate or even as continuous at a varying rate. Probably the ice-front oscillated, as we know is the case with modern glaciers, and one lobe may even have advanced while others retreated, as some Alpine glaciers are shown to have done in the last century.

As regards differential elevation less is known, but the numerous marine terraces of the lower Saint Lawrence may imply an intermittent elevation, each terrace indicating a halt or a slowing up of the motion. On the other hand, many of the terraces on the north shore of lake Superior and on Michipicoten island show beach ridge after beach ridge with no sharp line between, often running almost continuously upward as one goes inland and covering a range of from 50 to 100 feet. In fact, if one tabulates the various beaches one finds that at one point or another there are shorelines at every level from the present lake to 475 feet above it, with no gap greater than 10 feet between the successive steps.* Above this, however, the intervals become greater and more irregular.

We know little of these earth movements, but it is possible that they begin haltingly, grow more rapid and uniform, and then slow down irregularly as the brakes are applied. Following the common opinion that the solid crust or lithosphere resting on the layer of plasticity or tektosphere, to use Murray's terms, does not yield instantly to the change of conditions, there may be comparatively sudden accommodations when the strain goes beyond endurance, and then periods of relative quiescence.

If the theory held by Mr Warren Upham and others is correct that the oscillations of level are produced by the loading down of the region with ice, producing subsidence, and then the removal of the load by the melting of the ice, allowing it to rise again, there should be a rough correspondence between the thickness of the ice-sheet and the level of the land, though we should expect the stage of elevation to be always in arrears, perhaps even to the extent of thousands of years. Doctor Gilbert's researches appear to show that the region is still being tilted up toward the northeast, though the Great lakes are supposed to have been free from ice ever since Niagara falls began its work.

The mechanism by which these changes of level are produced is, of course, obscure, but it may be supposed that as the region becomes weighted down the plastic layer some miles below the surface yields to the pressure and moves sluggishly outward in all directions, and after relief from pressure creeps back to the area that has been lightened.

* Ont. Bur. Mines, 1899, pp. 155, 156.

The subject is, however, too extensive and too vague to be discussed properly here, and has been introduced only to indicate the complexities of the problem presented by the great series of raised beaches.

The theory of ice-dams as causing the old water-levels seems preferable to the older one still held by some geologists, that the beaches were all formed at sealevel, and has been adopted in this paper, since it is scarcely conceivable that marine fossils should swarm as they do in deposits up to the level of 350 or 440 feet and suddenly cease above that level.

Those who consider the beaches marine may reply, of course, that the seashells which once existed in the higher beaches have all been leached out by percolating waters, or that shells were never deposited in them, owing to the difference in conditions, such as the coldness or brackishness of the waters in contact with the edge of the ice.

While it is true that the higher beaches are, in general, older than the lower deposits which have abundant shells, and so may have suffered more from weathering, it must not be forgotten that the comparatively ancient Algonquin sands near Georgian bay are often crowded with freshwater shells still in perfect preservation, though somewhat fragile. On the other hand, the supposition that the seawater was lifeless when the upper beaches were made seems hard to defend. The coldness of the water does not affect the matter, for arctic seas swarm with life almost as much as temperate or tropical ones; nor can one assume that the water of a sea that must have been connected by broad and deep channels with both Hudson bay and the Atlantic could be made so brackish as not to support marine life, when the later comparatively narrow and shallow inlet west of Montreal left beds filled with shells, in spite of the pouring in of fresh water from the upper lakes.

The objection sometimes made to the theory of ice-dams that no glacial mass could withstand the pressure of a head of water hundreds of feet in depth, and that the lakes would soon find an outlet beneath the ice, does not seem well taken, for no one knows how effective a dam a sheet of ice 100 miles broad and a thousand or several thousand feet thick would make. The modern glaciers whose ice-dammed lakes have been studied are too insignificant relatively to make a comparison of much value. As to the head of water to be held up, one may just as fairly assume a low one as a high one, for it is admitted that the whole region stood lower at the time the beaches were formed than now, and the depression may have been great enough to relieve the dam of much of the pressure. It is quite unnecessary, therefore, to assume an ice-dam holding up a huge lake 1,400 feet above sealevel, so as to form a beach now at that

level, for the region may have risen most of the 1,400 feet since that time. In fact, the highest beaches may have been made at a time of great depression, and hence very little above the sea, while the lower and later ones may have had nearly the same position, owing to the advance in elevation as the ice-sheet thinned and retreated.

The later and lower deposits, which are clearly marine, were formed after the ice had been completely removed from the province of Ontario, and the climate of Ottawa had become practically the same as at present. These deposits are therefore in no sense interglacial.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 147-164 APRIL 13, 1901

PALEOZOIC LIMESTONES OF KITTATINNY VALLEY, NEW JERSEY*

BY HENRY B. KÜMMEL AND STUART WELLER

(*Read before the Society December 28, 1900*)

CONTENTS

KITTATINNY VALLEY

Kittatinny valley is the name given to that part of the Great Appalachian valley which traverses northern New Jersey. Its width varies from 10 to 13 miles, and it stretches from the Delaware river to the New York

* Published by permission of the State Geologist of New Jersey.

state line. On the northwest it is bounded by the Kittatinny mountain, the crest of which is composed of hard Oneida conglomerate and sandstone. On the southeast lie the pre-Cambrian crystallines of the highlands, while the rocks of the valley are chiefly limestones and shales of

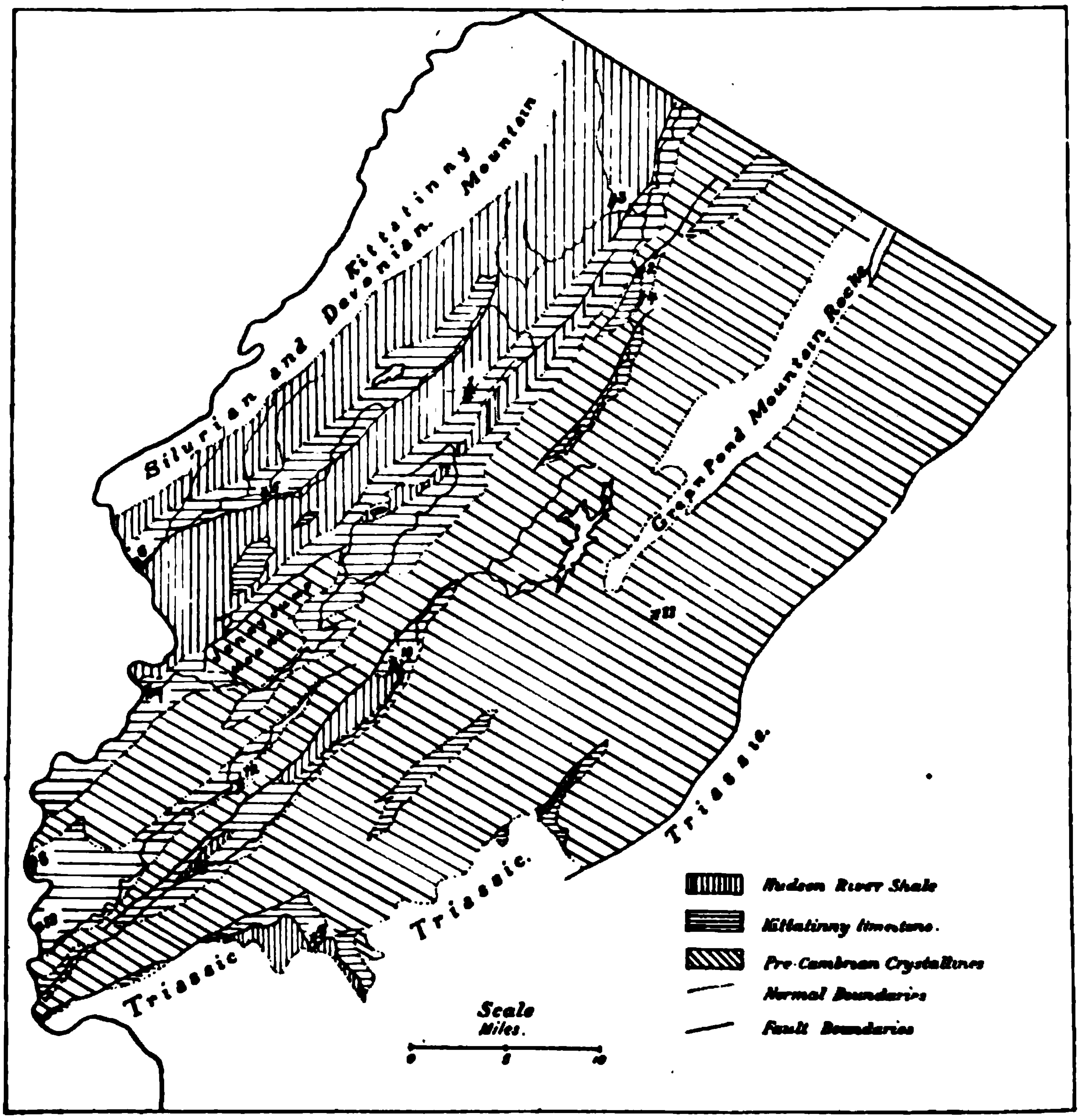


FIGURE 1.—*Map of Northwestern New Jersey.*

1. Newton. 2. Hamburg. 3. Deckertown. 4. Hardistonville. 5. Blairstown. 6. Columbia. 7. Belvidere. 8. Phillipsburg. 9. Hackettstown. 11. Dover. 12. Washington. 13. Carpentersville. The Hardiston quartzite forms a narrow outcrop along the normal contact of the Kittatinny limestone and the crystallines. The Trenton limestone forms a narrow outcrop along the normal contact of the Kittatinny limestone and the Hudson River shale.

Cambrian and Ordovician age. In addition to this wide trough-like depression there are several long, narrow valleys within the highlands themselves, the rocks of which are of the same age as those of the Kittatinny valley. Small detached areas of the same formations occur along

the eastern border of the highlands, and evidently underlie in part, at least, the Newark formation.

The general geological relations are shown in figure 1, which represents the northwestern part of the state, including the highlands, Kittatinny valley, and Kittatinny mountain. In the Kittatinny valley there is found the succession noted in the pages which follow.

Hardiston Quartzite

Relations and Character

At the base of the limestone, resting upon the pre-Cambrian crystallines, there is a sandstone or quartzite of variable composition and thickness. It was described and named Hardistonville quartzite by Wolf and Brooks,* from the village of that name, near which there are good exposures. The shorter name used above, which is that of the township, seems preferable, however, and is here proposed.

The following description of this formation † for the Franklin Furnace area was given by Wolf and Brooks:

"When fresh the quartzite is usually bluish gray, weathering near the surface to a yellow or brown, often porous, limonitic rock. Frequently it contains considerable pyrite, and varies in coarseness from a fine conglomerate to a quartzite. A shaly phase is often present in the upper part of the bed, where it merges into the limestone. It is composed of large and small grains of clastic quartz, which are usually cemented by calcite, mixed with a fine aggregate of quartz. In many localities it is filled with fragments of clastic feldspar (microcline, etc.), and plates of light colored mica which are distinctly clastic, as seen in thin section. Where it occurs near the white limestone it frequently contains graphite . . . in round plates, often bent, and in thin section they show no evidence of having been formed *in situ*. . . .

"The quartzite in many places becomes an arkose, and is then composed of quartz, feldspar, and mica, with fragments of granite."

These workers also found a few pebbles of white limestone imbedded in the quartzite at three localities.

Examination of the formation over a wider area has shown that it is even more variable in character than implied in the above extract. Some beds are composed of coarse rounded quartz grains, with some feldspar, the interstices being but slightly filled by any cementing material. In some sections the only approach to a quartzite is a coarse quartz sandstone or a fine grained sandy limestone, intercalated with beds of shale and dolomitic limestone. Elsewhere, as in the railroad

* U. S. Geol. Survey, 18th Annual Report of the Director, pt. ii, p. 442 et seq.

† Loc. cit., p. 442.

cut west of Hamburg station, a true quartzite occurs. Here a thin band of slightly arkose, vitreous quartzite is shown resting upon the granite.

Drift conceals all exposures for 10 or 12 feet, beyond which there are calcareous sandstones and sandy limestones for 45 or 50 feet. Fifty feet higher in the series a shaly limestone is exposed in an old quarry. Near Allamuche an arkose conglomerate occurs at the base of the formation. Pebbles 2 to 4 inches in diameter occur, although they are usually less than one inch. Pebbles of slate were noted in addition to the quartz, feldspar, mica, granite, and gneiss commonly present.

The quartzite is usually a blue-gray color when fresh, but some beds are a light yellow-brown, and others are nearly white. The arkose conglomerate layers vary considerably, owing to the varying shades of color of their constituents.

The thickness of the formation as given by Wolf and Brooks is from "30 feet to a foot or less." In our wider studies it has frequently been found to have a much greater thickness. The conglomeratic phase is known to exceed 100 feet at a number of localities. In the railroad cuts at Washington, New Jersey, where the quartzite can be seen to rest on the slightly undulatory surface of a coarse grained pegmatitic granitoid-gneiss, it has a thickness of 100 feet, grading upward into a sandy limestone, of which 15 feet are exposed, and which is in turn succeeded by at least 10 or 15 feet of sandy shales. If these transition beds are to be included in the quartzite formation, its thickness here is at least 140 feet. Thin beds of shale, sandstone, and impure limestone have elsewhere been noted at about the same distance, 120–140 feet above the base of the formation. North of Clinton, on the southeastern flank of the highlands, the conglomeratic quartzite is over 185 feet thick, the top not being exposed and the transition beds not being included in the measurement.

The varying constitution, the local derivation of the material, and the great range in thickness indicate that the conglomerate is a shore deposit. Its increase in thickness toward the southeast locates the Cambrian land in that direction. Its occurrence on the southeastern flank of the highlands proves that the land lay farther east than the present highlands and probably even east of the present limits of the state.

Lower Cambrian trilobites have been found by Beecher, Foerste, and others in this formation near Franklin Furnace and Andover, and by Weller at various points from Franklin to Washington. They can be recognized only in the calcareous sandstone beds and here only in the weathered portion of the rock, from which the calcareous matter has been dissolved. This weathered rock is of a deep brown color, arenaceous and friable. It splits readily along the planes where the trilobite

tests have been removed by solution during the process of weathering. A careful search in the fresh, unaffected portion of the rock failed to disclose any sign of fossil remains. That they are really present in abundance, however, is shown by the frequency of their occurrence in the weathered portions. We have found no fossils in the vitreous quartzites nor in the arkose beds.

PREVIOUS VIEWS

Professor Rogers * observed this formation at a few localities and called it number 1 of the Lower Secondary or Appalachian rocks.

Professor George H. Cook † correlated it with the Potsdam sandstone of New York on the basis of its position beneath the great limestone formation, all of which was believed to be the equivalent of the Calciferous sandstone of New York.

In 1890 F. L. Nason, in a paper presented to the Geological Society of America, announced the discovery by himself and Doctor Beecher of Lower Cambrian fossils in this quartzite.

Doctor Foerste ‡ in 1893 added to the localities at which Cambrian fossils had been found and showed that the quartzite bed was more continuous than had been previously supposed.

C. D. Walcott § has shown that "the basal sandstones of Alabama, Tennessee, and Virginia (Chilhowee quartzite); Maryland, Pennsylvania, and New Jersey (the Reading quartzite); New York and Vermont (Bennington quartzite), were all deposited in Lower Cambrian time."

Wolf and Brooks || described the formation as it occurs near Franklin Furnace, New Jersey, and applied to it the geographical name "Hardistonville."

Kittatinny Limestone

STRATIGRAPHIC AND MACROSCOPIC CHARACTERS

Above the Hardiston quartzite and lying conformably on it is a great thickness of limestone, mostly dolomitic and unfossiliferous. Nearly all the limestone of both the Kittatinny valley and the allied highland valleys is included in this formation. It is somewhat variable in texture, bedding, and color, but these variations are not sufficiently constant to afford a basis of further subdivision. The color is usually blue or gray. Sometimes it is nearly black, and in places it has a pinkish tinge. Much of the formation occurs in massive beds, occasionally 3 or 4 feet thick.

---

* Description of the Geology of New Jersey, being a final report, Phila., 1840, pp. 45–47.
† Geology of New Jersey, 1868, p. 72.
‡ Foerste: Am. Jour. Sci., 3d series, vol. xlvi, 1893, pp. 435–444.
§ Walcott: Bulletin 134, U. S. Geol. Survey, 1896, p. 33.
|| Wolf and Brooks, loc. cit.

Contrasted with these there are several hundred feet of thin beds in the upper part of the formation in which bands of limestone an inch in thickness are separated by thin partings of greenish shale or by equally thin layers of sandstone. Some layers contain much chert, both in the form of nodular masses and as lenses a foot or less in thickness and several rods in diameter. Some beds are minutely crystalline, some of so dense and fine a texture that no grains nor crystals are visible macroscopically, and some of the lower beds are oolitic. At a number of points beds of almost pure limestone, alternating with the dolomitic layers, occur near the top of the formation as exposed. Owing to a slight unconformity, however, between this formation and the succeeding one, the top is a variable horizon.

The thickness of the Kittatinny limestone is probably about 2,700 to 3,000 feet, although owing to folds and faults no absolutely reliable estimates can be made; but the figures obtained are not discordant with estimates made in other states.

CHEMICAL COMPOSITION

Many analyses * of this limestone have been made by the New Jersey Geological Survey at various times, so that its chemical composition is well known. Nearly all the analyses, which are of specimens from widely scattered localities and different horizons, contain a large amount of magnesia, whence the name magnesian limestone, applied by Doctor Cook. Thirty-nine analyses showed the composition to vary within the following limits:

SiO_2 (silicic acid and quartz)	1.8 to 15.0 per cent.
Fe_2O_3 / Al_2O_3	0.6 to 8.4 per cent.
CaO	23.6 to 32.4 per cent.
MgO	14.6 to 21.7 per cent.

In the upper part of the formation a few thin layers of a purer limestone, with 90 per cent or more of carbonate of lime, alternate with the dolomite.

FAUNA OF THE KITTATINNY LIMESTONE

The calcareous sandstones forming the top of the Hardiston quartzite pass insensibly into the lower arenaceous limestone of the Kittatinny formation, but the Lower Cambrian fauna of the quartzite has not been recognized in the Kittatinny limestone. The age of the beginning of the continuous Hardiston-Kittatinny sedimentation may be definitely fixed as Lower Cambrian.

*As the analyses were usually made for economic purposes the better layers were probably chosen and the markedly impure shaly or sandy layers rejected.

In the midst of the limestone, fossils have been found in but four localities worthy of mention, although fragments of trilobites and brachiopods have been observed elsewhere. Just north of Blairstown a thin stratum was found containing a large number of individuals apparently belonging to but two species of trilobites. No entire specimens have been seen, both species being represented by cranidia, free cheeks, and pygidia. Our species is apparently undescribed and is probably referable to the genus *Ptychoparia*. The other, a much larger one, resembling the illustration of *Bathyurus armatus*, Billings,* but without the occipital spine, may be identified as *Agraulos saratogensis* Walc. The Upper Cambrian age of the bed containing these two trilobites is assured.

In O'Donnell and MacManniman's quarry, at Newton, a fauna of about ten species of brachiopods and trilobites was collected, which indicates the Upper Cambrian age of the enclosing sediments at that locality. Among the trilobites, a species of *Dikelocephalus* is by far the most abundant form, some fragments of which are of such a size as to indicate the presence of individuals having a breadth of head of several inches. A single broken cheek was found which seems to be indistinguishable from similar specimens in the Hardiston quartzite referred to the genus *Olenellus*. If additional specimens should confirm this identification, this occurrence of the two genera, *Olenellus* and *Dikelocephalus*, associated together, would be a notable one.

At Carpentersville, south of Phillipsburg, in one of the outlying areas of the Kittatinny limestone, Cambrian trilobites were found, and the species *Liostracus jerseyensis* has been described † from there, although it is quite probable that the generic reference is erroneous.

In the railroad cut at Columbia, on the Delaware branch of the New York, Susquehanna and Western railroad, a very different fauna was collected from a bed in the upper portion of the Kittatinny limestone. On the hillside above the cut, the overlying Trenton limestone is exposed, so that this fauna must occur within a few hundred feet of the summit of the formation. The fauna consists in large part of gasteropods, and the following preliminary identifications of the species have been made:

1. *Syntrophia lateralis* Whitf. ?
2. *Dalmanella* sp. undet.
3. *Platyceras* sp. undet.
4. *Metoptoma quebecensis* Bill.?
5. *Ophileta complanata* Van. ?
6. *Eccyliomphalus* sp. undet.
7. *Raphistoma* cf. *R. staminea* Hall.
8. *Cyrtoceras* cf. *C. confertissimum* Whitf.
9. *Asaphus canalis* Con.
10. *Illænurus* sp. undet.

* Geol. Survey Canada, Pal. Foss., vol. 1, p. 411, fig. 392.

† Geol. Survey N. J., Ann. Rept. State Geol., 1899, p. 51, pl. 1, figs. 1–8.

Although these identifications are but provisional, the whole complexion of the fauna is recognized as Calciferous, and on this evidence there can be no hesitation in correlating the upper portion of the Kittatinny limestone with the Calciferous. The evidence of the fossils therefore establishes the age of the Kittatinny limestone as including a part of the Lower Cambrian, the Middle and Upper Cambrian, and extending into the Calciferous. A study of the stratigraphy seems to indicate that there was no break in the sedimentation during this long period of time.

PREVIOUS VIEWS

Professor Rogers* included both the Kittatinny and the overlying Trenton limestone in his formation, number 2, of the Lower Secondary rocks. It is the magnesian or blue limestone of Professor Cook's† reports, and it was by him regarded as the equivalent of the Calciferous of New York. Prime‡ concluded that the Magnesian limestones found in the extension of the Kittatinny valley into Pennsylvania "correspond in age to the Calciferous and Chazy epochs." The discoveries by Walcott,§ Dwight,|| and Dana of Lower Cambrian fossils in the lower portions of the same limestone in Pennsylvania and New York finally led to correct inferences as to the Cambrian and Lower Ordovician age of these rocks in New Jersey. Our determinations now confirm these inferences.

Trenton Formation

This formation consists of non-magnesian limestones and calcareous shales, with a local calcareous conglomerate of varying thickness at its base.

Basal Conglomerate

Resting on the slightly eroded surface of the Kittatinny limestone there is a basal conglomerate composed of pebbles of the underlying magnesian limestone and chert. It is not everywhere present in equal development, but it is practically coextensive with the Trenton limestone in New Jersey. Where observed it varies considerably in character and thickness. It is sometimes merely a thin layer of small well rounded magnesian limestone pebbles in a purer limestone matrix, which occa-

* Rogers: Loc. cit.

† Cook: Loc. cit., p. 90.

‡ Prime: Pennsylvania Second Geol. Survey, D 3, vol. i, p. 163.

§ Walcott: Loc. cit., p. 33.

|| Dwight: Am. Jour. Sci., 3d series, vol. xxxi, p. 125 et seq.; vol. xxxiv, p. 27 et seq.; vol. xxxviii, p. 139.

sionally contains Trenton fossils. It is sometimes represented only by a few scattered pebbles in the lower beds of the Trenton limestone. Elsewhere it may be 30, 50, or even 100 feet in thickness, and the water-worn fragments may exceed even 2 feet in diameter. In such instances lenses of lime "sandstone" occur in the conglomerate, together with thin layers of limestone bearing many segments of crinoid stems. In still other localities its constituents are large and angular, showing evidence of accumulation by waves *in situ*, with practically no transportation. On the weathered surface of such a bed the outlines of the fragments can not readily be seen, and it is not easily distinguished from a jointed and crushed bed of the Kittatinny limestone. Although the maximum observed thickness of this conglomerate is about 100 feet, with neither top nor base exposed, the usual thickness is only a few feet.

Good exposures are found (1) three-fourths of a mile east of Branchville, (2) just north of Newton, (3) at the northeast end of Jenny Jump mountain, near Southtown, (4) a mile east and southeast of Hope, (5) along the road one and a half miles northeast of Hope, and (6) along the railroad one-half mile north of Belvidere. It may be seen also at many other places along the line of the Trenton outcrop, which usually forms a narrow strip between the overlying slate and the Kittatinny limestone.

Walcott* has described certain conglomerates in the Cambrian limestones of Pennsylvania and elsewhere, which he has called intraformational, and which are defined as conglomerates "formed within a geologic formation of material derived from and deposited within that formation." Discontinuous beds of such conglomerates, some of a brecciated nature, have been observed at various points in the Kittatinny limestone, but the beds described above can not be put in that class for the following reasons:

First. The pebbles are limestone and chert, from the underlying dolomitic formation, which is not known to contain fossils of later age than the Calciferous. The matrix, on the contrary, is a much purer limestone and contains Trenton fossils (though not abundantly), and the associated limestone layers are very low in magnesia and contain a well marked Trenton fauna.

Second. The conglomerate rests unconformably on the underlying formation. So far as known the contact is exposed only at the Sarepta quarry, 3 miles northeast of Belvidere, where the conglomerate beds are not strictly conformable to the underlying layers, but dip northwestward at a slightly greater angle. The contact, although not sharply

* Bulletin 134, U. S. Geol. Survey, pp. 34–40.

marked, is distinctly oblique to the underlying beds. The fragments in the lower layers of the conglomerate are coarse and angular, surrounded by a matrix of smaller fragments of the same sort, and have evidently undergone but little transportation and sorting. In the upper beds the fragments are smaller, better rounded, and the matrix carries crinoid stems and other obscure fossils. Above the conglomerate is found the typical Trenton limestone, through which are scattered occasional Kittatinny limestone pebbles. In other localities the dips of closely adjoining beds of Trenton and Kittatinny formations are not more discordant than might be expected in conformable formations which have been more or less closely folded.

Trenton Limestone

Character and Thickness

The Trenton limestone proper rests either directly on the Kittatinny limestone or on the basal conglomerate. It is a dark blue or black, non-magnesian limestone, in massive beds, generally weathering into thin, knotty, irregular layers, a few of which are minutely crystalline. Some of these layers contain as high as 95 per cent carbonate of lime. Intercalated with the purer limestones are more shaly beds, and the whole formation grades into the overlying clayey, micaceous, slate, and sandstone formation through a series of calcareous shales, which are sparingly fossiliferous and commonly concealed by glacial drift or wash from the harder and topographically higher layers. It is this calcareous shale which forms the "cement rock" of the Lehigh and Phillipsburg Portland Cement regions. These calcareous shales, with the occasional thin bands of limestone which occur in them, are classed with the underlying fossiliferous limestones, rather than with the overlying argillaceous slates, although there is no sharp line of demarkation between them.

In the northern and central part of the Kittatinny valley the thickness of the Trenton is about 135 feet, but it increases toward the southwest, being 300 feet or more near the Delaware and apparently something more than that in the Lehigh region, Pennsylvania. The increase in thickness is due apparently to the increase in the thickness of the calcareous shales, the cement rock at the top, rather than of the purer, massive, fossiliferous limestones below.

Chemical Composition

The Trenton limestones are not magnesian, as is the great mass of the Kittatinny formation. The purest layers contain 52 to 55 per cent of

lime (CaO) (out of a possible 56 per cent), less than 0.5 per cent of magnesia (MgO), less than 1 per cent of iron and alumina, and 1 to 2 per cent of silica and other insoluble matter. The less pure limestones contain larger amounts of silica and of iron and alumina, a part of the silica being probably due to the presence of sand.

In the transition to the overlying Hudson River series, beds of exceedingly variable chemical composition may be found. The composition of the calcareous shales, so widely used for the manufacture of Portland cement, is approximately as follows:

SiO_2	10.2 to 20.5 per cent.
Al_2O_3 / Fe_2O_3	5.4 to 7.9 per cent.
CaO	39.7 to 44.8 per cent.
MgO	0.4 to 1.4 per cent.

Trenton Faunas in New Jersey

THE FAUNAL SUCCESSION

Several distinct faunal zones have been recognized in this formation. Its outcrops, however, are so isolated and are usually so fully covered with débris that fossils can be collected only from loose fragments of the limestone on the surface. It is also rare to find more than a single faunal zone in any one outcrop. Under these circumstances the determination of the exact succession of the faunal zones is a problem of some difficulty. The investigation of the succession of these zones has been only just begun, and further study will undoubtedly add much to the results which can be announced at the present time. Enough has been determined, however, to suggest a general correlation between the Trenton formation as it occurs in New Jersey and New York.

The lowest definite horizon in the Trenton at which fossils have been found occurs at a locality a little over two miles southeast of Newton.* The basal conglomerate is but slightly developed, or is wanting at this locality, and in a bed lying but a few feet from the Kittatinny limestone the following fossils were collected:

1. *Streptelasma profunda* (H.).
2. *Strophomena incurvata* (Shep.).
3. *Ctenodonta nasuta* (H.).
4. *Hormotoma gracilis* (H.).
5. *Orthoceras* sp. undet.
6. *Bumastus trentonensis* (Emm.).
7. *Calymmene senaria* Con.
8. *Arges?* sp. undet.
9. *Leperditia fabulites* (Con.).

*The exact locality is on the northwest slope of the 663-foot hill, about three-fourths of a mile north of the southwestern end of Iliff's pond. Sheet 1, New Jersey Topographical Atlas.

Leperditia fabulites, a Black River species of ostracode, is the most abundant form, occurring in great numbers, almost to the exclusion of the other species. The complexion of the fauna, as a whole, is Black River, although none of the species are typically restricted to that horizon.

On the same hillside, lying stratigraphically 25 or more feet above the Leperditia horizon, but below it topographically, there is quite a different faunal zone with *Parastrophia hemiplicata* (Hall). This *Parastrophia* zone also occurs in an outcrop just north of Drake's pond, east of Newton, where the fauna is much better represented, and the following species were collected.:

1. *Columnaria* sp.
2. *Lingulasma* sp.
3. *Plectambonites sericeus* (Sow.).
4. *Strophomena incurvata* (Shep.).
5. *Orthis tricenaria* (Con.).
6. *Dinorthis pectinella* (Emm.).
7. *Dalmanella testudinaria* (Dal.) var.
8. *Platystrophia biforata* (Schl.).
9. *Parastrophia hemiplicata* (Hall).
10. *Pterygometopus callicephalus* (Hall).
11. *Bumastus trentonensis* (Emm.).
12. *Isotelus gigas* (De Kay).
13. *Platymetopus trentonensis* (Hall).

In his study of the Trenton faunas in New York, White * has found a Parastrophia zone to be quite constantly present at the top of the Black River horizon, and it is possible that the Parastrophia zone in New Jersey is a southern continuation of the same zone as it occurs in New York. Too much dependence, however, should not be placed upon the occurrence of *Parastrophia hemiplicata*, for the same species is known to occur even as high up as the Lorraine. *Orthis tricenaria* and *Dinorthis pectinella*, however, which occur in the fauna, are characteristically low Trenton forms, and *Columnaria* is usually considered as being typical of the Black River horizon.

Another faunal zone in the Trenton of New Jersey, which is apparently widespread, is characterized by a species of *Receptaculites*, probably *R. occidentalis* Salt. Because of the isolated nature of the outcrops, this Receptaculites zone has never been noticed in close association with any other zone, so that its exact position has not yet been definitely fixed, although it has been observed at many different localities. It is certainly in the lower portion of the formation and is probably beneath the Parastrophia zone. *Streptelasma profunda* and *Columnaria* usually occur associated with the *Receptaculites*.

The most prolific Trenton fauna in New Jersey, so far as observed, occurs on the summit of the hill northwest of Jacksonburg, a small village near Blairstown. This fauna occupies the highest position in

* Rep. of Director N. Y. State Mus., 1900, p. 28.

the formation of any yet noticed in New Jersey, and contains, in part, the following species:

1. *Hindia parva* (Ul.).
2. *Streptelasma profunda* (H.).
3. *Orbiculoidea lamellosa* (H.).
4. *Schizocrania filosa* (H.).
5. *Dalmanella testudinaria* (Dal.) var.
6. *Plectambonites sericeus* (Sow.).
7. *Dinorthis pectinella* (Emm.).
8. *Strophomena incurvata* (Shep.).
9. *Rafinesquina alternata* (Emm.).
10. *Rhynchonella inæquivalvis* (Castel.).
11. *Rhynchotrema dentata* (H.).
12. *Zygospira recurvirostris* (H.).
13. *Cuneamya truncatula* (Ul.).
14. *Whitella ventricosa* (H.).
15. *Ctenodonta nasuta* (H.).
16. *Ctenodonta nitida* (Ul.)?
17. *Ctenodonta levata* (H.).
18. *Clidophorus neglectus* (H.).
19. *Allodesma subellipticum* (Ul.)?
20. *Modiolopsis faba* (Con.).
21. *Bucania punctifrons* Emm.
22. *Tetranota bidorsata* (H.).
23. *Protowarthia cancellata* (H.).
24. *Conradella compressus* (Con.)?
25. *Archinacella patelliformis* (H.).
26. *Liospira subtilistriata* (H.)
27. *Eccyliomphalus trentonensis* (H.).
28. *Eccyliomphalus contiguus* Ul. ?
29. *Holopea obliqua* H. ?
30. *Holopea supraplana* U. and S. ?
31. *Holopea symmetrica* H.
32. *Lophospira obliqua* Ul.
33. *Hormotoma gracilis* (H.).
34. *Pterotheca expansa* (Emm.)?
35. *Conularia trentonensis* H.
36. *Harpina ottawensis* (Bill.).
37. *Trinucleus concentricus* (Eaton).
38. *Bronteus lunatus* Bill.
39. *Dalmanella achates* Bill.
40. *Pterygometopus callicephalus* (H.).
41. *Prœtus* sp. cf. *P. parviusculus* H.
42. *Bumastus trentonensis* (Emm.).
43. *Calymmene senaria* Con.
44. *Isotelus gigas* De Kay.
45. *Ceraurus pleurexanthemus* Green.
46. *Platymetopus trentonensis* (H.).
47. *Odontopleura parvula* (Walc.).

This fauna is apparently a well defined, typical Trenton fauna, and probably should be referred to about the middle Trenton.

CORRELATION WITH NEW YORK TRENTON

From the paleontologic evidence at hand, it can be quite definitely stated that the Trenton limestone in New Jersey represents the lower portion of the Trenton limestone of New York, including the Black River limestone, which is in reality nothing more than the basal portion of the Trenton. It is probable, also, that it does not represent the entire Trenton limestone as that formation occurs in its typical area in New York, but that the conditions for the deposition of the overlying shales and sandstone, which we call the Hudson River formation, were initiated earlier in this region than in the typical Trenton area.

PREVIOUS VIEWS

The Trenton age of the upper portion of the great limestone formation was recognized by Cook * and termed by him the fossiliferous limestone.

* Cook, loc. cit., p. 131.

The determination of its age was in fact the basis on which the magnesian limestone and the "Potsdam" sandstone were referred to their respective horizons. Foerste's* later observations confirmed the correctness of the earlier determinations. Rogers observed the basal conglomerate as early as 1855, at a point where it had been faulted against the crystallines. Brief mention of it has occasionally been made in the Geological Reports of the state geologist of New Jersey, but its stratigraphical importance has not previously been recognized.

Structure

Folds and Faults

In the Kittatinny valley the rocks lie in several large open folds, the three main limestone areas forming anticlines, and the slate belts between them synclines, with axes trending northeasterly. Although in general the structure is thus very simple, in detail it is much more complex. Minor folds occur within the larger ones, more commonly in the overlying slate than in the limestone. These are frequently closely compressed, and vary in radius from a few feet to several rods, or even half a mile. The dips are usually steeper on the southeastern flank of the folds than on the northwestern, so that the axial planes must dip steeply to the northwest.

Thrust faults occur on the flanks of the folds in a number of cases, cutting out the narrow outcrop of Trenton limestone. The slate belt east of Newton is but half a syncline in its northern part, the westward half having been faulted off. The anticline of Kittatinny limestone along the Paulinskill has been faulted along its crest in such a way as to preserve a narrow strip of the Trenton limestone and conglomerate in the midst of the older formation.

West of Jenny Jump mountain—a huge island of gneiss in the midst of the Paleozoics, forming a detached portion of the highlands within the valley—faulting seems to have been more severe than elsewhere. A fracture along the western side of the mountain brings the Kittatinny and the Trenton limestones, as well as the Hudson River slate, successively against the gneiss. Elsewhere several small areas of the Kittatinny limestone are surrounded by the shale, and apparently rest on it, their position being probably due to thrust faults of considerable extent. At other points, also, the shale has been undoubtedly shoved over on the limestone. The fault planes are rarely exposed, and in many instances the direction and amount of the hade can not be determined. In the few cases observed northwest hades are more common than any other.

* Foerste, loc. cit.

In the inter-highland valleys, as was long since pointed out by Doctor Cook,* the folds are more compressed and are frequently overturned on the southeastern flank. In fact, so complex is the structure through close folding and faulting that it is next to impossible to work out the details. Still further to the southeast, along the border of the highlands, the exposures of the Paleozoic rocks are generally very meager and the structure complex. In a railroad cut near Clinton eighteen faults in the Hudson River slate were noted in a space of one hundred yards. They were at all angles, from nearly vertical planes to nearly horizontal thrusts.

CLEAVAGE

The more massive beds of the Kittatinny limestone show no signs of cleavage and usually no indications of shearing. Some of the thinner layers are obscurely cleaved, the cleavage planes usually dipping southeastward. The thin partings of shale which so frequently occur in some parts of the formation are very commonly sheared, showing that in the folding the layers slid past each other along their bedding planes.

The Trenton beds commonly show signs of shearing, even in the more massive layers. The shear planes usually dip steeply to the southeast. In many cases the fossils are distorted, and a marked fissility has been developed.

The Hudson River formation is usually everywhere so strongly cleaved, except in the case of the heavy sandstone layers, that the bedding is not readily distinguishable. Although the dip of the cleavage planes is most commonly to the southeast and crosses the bedding planes at constantly varying angles, yet this is not always the case. The cleavage is sometimes nearly horizontal and not infrequently to the northwest. In some exposures it is curved. Since the study of the Hudson River slates is far from complete, it is not possible to say whether there has been a continuation of the folding since the cleavage was formed, whereby the planes of cleavage have taken different attitudes, or whether in the folding the pressure was transmitted in such different directions that the cleavage was developed in planes at various angles and directions of dip.

CONDITIONS OF SEDIMENTATION

The Hardiston quartzite indicates shore conditions near at hand. The varying lithological character of the formation, as well as its great range in thickness, often apparently within narrow geographical limits, indicates a wide range of conditions, such as would only prevail close to shore.

*Geology of New Jersey, 1868.

The greater thickness of the formation at its southeastward exposures, as compared with the westward outcrops, points to the existence of land to the southeast of the present highlands, conclusions which are in accord with those of workers in Pennsylvania and farther south.

During the formation of the Kittatinny limestones the waters were not deep, as wave marks occur at various horizons. The thin partings of shale or of sandstone in the limestone show that at intervals land derived mechanical sediments were present in sufficient amount to interrupt the formation of the dolomite; but in general the sea was remarkably free from sediment. The limestone exposed within the highlands or along their southeastern flank do not in themselves show a greater proximity to a shore than do those of Kittatinny valley, 20 miles or more to the northwest, and therefore that distance farther from the shoreline of that period. During this time the shore must have lain far east of its position during the formation of the Hardiston quartzite and a considerable distance east of the borders of New Jersey. In this, also, our studies are in accord with the conclusions of those who have studied these limestones farther south.

During the later stages of this period changes in the sea began, in consequence of which non-magnesian limestones alternated in deposition with the dolomites. Leslie * has shown that in southeastern Pennsylvania dolomitic and non-dolomitic beds alternate in sharply differentiated layers in the lower middle of the formation, due, he thinks, to alternating conditions of deposition; but there is nothing in the analyses of the New Jersey limestones to indicate that the changes began as early as in Pennsylvania.

The Trenton conglomerate and the slight unconformity between it and the Kittatinny limestone indicate an uplift of the sea bottom, erosion, and the prevalence of shore conditions in northern New Jersey and the neighboring region to the north. Our own studies have not extended north of New Jersey, but the occurrence of the Trenton conglomerate in southeastern New York is clear from the studies of others.

An exposure of it two and a half miles north of Newburg, New York, is pictured by Ries,† although he does not mention it in his text. Concerning this outcrop Mr Gilbert Van Ingen, who took the photograph, writes: ‡

"The rock shown in the picture is a dark, impure limestone with many pebbles of the dolomitic lower Ordovician limestone. . . . The pebbles in the limestone are sometimes three inches in diameter."

* Second Pennsylvania Survey, M. M., pp. 360, 361.

† Report of the State Geologist of New York, 1895, report on Orange county, pl. xxxi.

‡ Personal letters to the authors.

Mr Van Ingen also reports outcrops of the conglomerate on the Jaycox farm, just north of Wappinger's falls. He says:

"Against this cliff (of dolomitic limestone) the Trenton was deposited. The line of contact is quite plainly seen and is rather irregular, with undercut projections. . . . The limestone here is partly a conglomerate of the dolomite pebbles and partly clear of these. . . . The peculiar feature of this locality is that the pebbles are not restricted to the lower layers, but occur at two or more levels, the intervening layers being either non-fossiliferous, dark, impure limestone or filled with the Solenopora. The true base of the limestone cannot be seen here, so that I was unable to determine whether it is conglomeratic or not. The pebbles are often large—five inches."

Dwight* also mentions a locality in the Wappinger valley, 2 miles southeast of Pleasant valley and 15 miles north of the above-mentioned locality, where the rock is "filled with limestone pebbles of various sizes and lighter in color than the mass." He states that many of these may have been organic, although no organic structure was visible. His words, however, describe exactly an exposure of the Trenton conglomerate. The occurrence of the conglomerate in Orange and Dutchess counties, New York, seems certain.

Although the conglomerate occurs beyond the limits of New Jersey to the northeast, it is, so far as our own brief observations and the writings of others go, absent to the southwest. In Pennsylvania and southward the Trenton beds follow those containing Calciferous and Chazy fossils with apparently no break in sedimentation. The region chiefly affected by the uplift, so far as data in hand show, was small as compared to the great extent of the Kittatinny limestone, and the movement gave rise, perhaps, to only a series of low, rocky islands and reefs, against which the waves beat and about which the conglomerate was formed; but the profound life change at this horizon, wherever the rocks of this age are exposed, even though the conglomerate and accompanying unconformity be not found, indicates something more than a local disturbance. The break in the record was long enough for the incursion of an abundant fauna of very different facies from that previously occupying the sea.

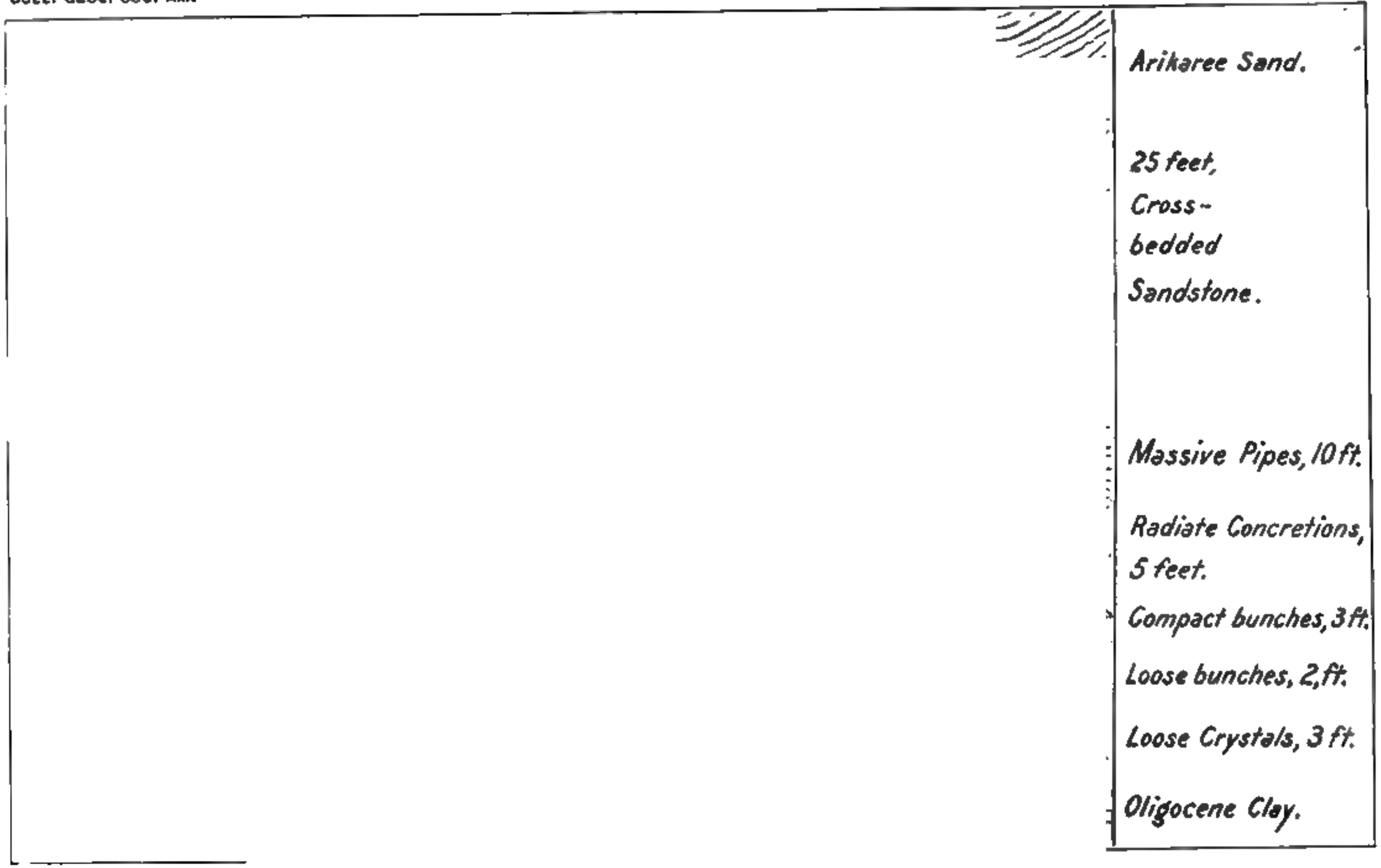
The passage from the Trenton limestone into the overlying shale and slate was due to changes prevailing along the entire Appalachian valley—changes which Mr Weller's faunal studies show were inaugurated in New Jersey earlier than in the typical Trenton area in New York.

Date of Folding and Faulting

So far as observed, there are in New Jersey no data showing absolutely

*Am. Jour. Sci., 3d series, vol. xvii, p. 390.

the date of the folding of these rocks. Slight unconformity between the Oneida conglomerate (Shawangunk grit) and the Hudson River shale is shown in the railroad cut at Otisville, New York, a few miles north of the New Jersey state line. This may mean that some folding took place at the close of the Ordovician. The greater disturbance, however, was undoubtedly at the close of the Paleozoic. Southeast of the highlands the Triassic rocks rest in part upon the eroded edges of these early Paleozoic formations. The profound faults of the former undoubtedly affect, in some instances, the underlying Paleozoics, but most of the faults in the Paleozoics along the borders of the Trias do not enter the latter, and are, therefore, older. If there was any disturbance in the Kittatinny Valley region during the Trias faulting, we have not been able to differentiate it from the earlier movements.



VIEW OF DEVIL HILL, SOUTH DAKOTA

Showing zones of sand crystals. Altitude by aneroid [illegible] feet. Vertical section to right

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 165-172, PLS. 13-18 APRIL 16, 1901

SAND CRYSTALS AND THEIR RELATION TO CERTAIN CONCRETIONARY FORMS*

BY ERWIN HINCKLEY BARBOUR

(*Presented before the Society December 29, 1900*)

CONTENTS

LOCATION AND GEOLOGICAL RELATIONS

Concretions of various kinds are abundant in several formations in the Great Plains region, and their prominence is so marked that facts which throw light on their origin are greatly to be desired. Recently there has been discovered in one of the Tertiary formations an exposure which exhibits in a most instructive manner the development of concretions by evident crystallization, which it is the purpose of this paper to describe.

The Tertiary of the Great Plains region comprises the White River group of the Bad lands, mainly of Oligocene age, and a great series of deposits which originally were included under the term Loup Fork. The greater portion of this series, extending through Nebraska into South Dakota, has been separated by Darton under the designation of Arikaree formation. It is believed to be of Miocene age. This formation consists mainly of sand which locally is consolidated more or less, but is in part loose and incoherent. The isolated portions give rise to many of the

* Acknowledgments are due to the Honorable Charles H. Morrill, whose generosity made this investigation possible.

buttes which are so prominent in southern South Dakota, northern and western Nebraska, and eastern Wyoming.

Mode of Occurrence

The formation is characterized by an abundance of concretions generally having the form of horizontal cylindrical masses which project from the walls of the buttes like guns from a fortress, and also by the occurrence in its upper member of numerous rootlets and vegetal fibers. There are concretions, as round as cannon balls, often scattered thickly over many acres of ground. These, however, usually pass into great aggregates of cylindrical form called pipes.

It is interesting to note the occurrence of every condition and every possible gradation from solitary spherical concretions to strings of partly united concretions, then to pipes, which we shall consider as made up of an infinite series of spherical concretions. Wind and rain supple-

Figure 1.—*Simple and compound Concretions and Pipes, northwestern Nebraska.*

ment each other in exposing considerable tracts of these concretions, and, in the case of the compound ones, which are sufficiently lithified to withstand long weathering, the exposure simulates the planed and deeply grooved surface of a glaciated region.

Physical Characters of the Concretions

The individual pipes vary in size from a hand specimen to those exceeding a hundred yards or more in length, and from the simple to the compound pipes. When weathered out, these impart to the landscape a singularly ragged and fantastic appearance even surpassing the weird effects produced by the erosion figures known as " hoodoos."

An exposure of the ordinary spherical type, if scrutinized, reveals the fact that many or all of the concretions are obscurely or distinctly radiate like radiate calcite. This is but the visible evidence of some internal molecular or crystalline arrangement. Even the loose and less coherent matrix reveals, under the action of wind and rain, an ill-defined, though unmistakably radiate, or rosetted structure. This effect is crystallographic, and is due, as is shown by inspection, solely to the calcium carbonate cement. At some stage of development the sands were evidently

FIGURE 1.—SAND ROCK ON DEVIL HILL

Composed of large radiating sand-lime concretions

FIGURE 2.—PORTION OF GREAT PIPE

SAND ROCK AND PORTION OF GREAT PIPE, DEVIL HILL, SOUTH DAKOTA

FIGURE 1.—TWINS, INTERPENETRATIONS, AND CLUSTERS

Figure 10, smallest sand crystals, each about 6 millimeters long

FIGURE 2.—SUCCESSIVE STAGES IN SAND CONCRETION BUILDING BY SAND CRYSTALS

Figure 5, broken concretion, showing radiate structure. In figure 6 identity of crystals is more obscure than usual

TWINS, INTERPENETRATIONS CLUSTERS, AND STAGES IN CONCRETION BUILDING

saturated with lime salts, which crystallized according to the laws governing calcite as far as interference on the part of the sand grains would allow, and in so doing cemented together the grains into concretions or pipes and into compound pipes, making fairly solid rock of local extent.

A general view of radiate concretions, as well as concretionary pipes, may be had in plate 14, figures 1 and 2. The evolution of the radiate concretion from the single sand crystal is shown in plate 15, figure 2. Plate 16 shows the surface and inner structure of several radiate concretions, figure 1 showing the surface and figure 2 the structure of a coarse specimen; figures 3 and 4 showing the surface and interior structure of a finer form concreted around large pebbles. Figure 5 is an end view, showing the radiate structure of the coral-like pipe seen in figure 2, plate 14. Figures 6, 7, and 8 are small radiate concretions from Sioux county, Nebraska.

Material from Devil Hill Region

But the most important light on this kind of development is given by the strata containing the sand crystals, or concretion crystals, as the writer first named them in 1893, in the south-central portion of South Dakota. Following the unbroken, sandy Arikaree north into South Dakota, one soon finds it cut into ridges and solitary buttes, and disappearing altogether within about 20 miles of the White river, one of the northernmost remnants being Devil hill, situated between Potato creek and Corn creek. Here, at an altitude of 3,600 feet (by barometer), on a lofty, isolated hill of White River clay, rests a thin Arikaree cap. The place bristles with grotesque erosion figures, ragged concretions, and pipes, together with loose sand and countless sand crystals so geometric in design as to attract the notice of the early Indians, who considered them supernaturally wrought for their destruction. Mingling our superstitions with theirs, they called the place Devil hill, a spot still viewed with unnatural dread and discreetly avoided.

The region is distant from railroads, and the collector who would visit this spot must plan for a trip, by team, of 3 or 4 days. Ranches owned by Indians are some 20 to 25 miles apart, but all necessary comforts and some luxuries can be secured in these Indian homes at a very reasonable rate, and the trip may be made with comfort. A guide is necessary, as the locality is remote, and it is often difficult to obtain satisfactory information from the natives.

The unique sand-lime crystals found exclusively in this spot, as far as known, are hexagonal barrel-shaped forms with rounded terminations. These were first made known to the writer in 1893 by the Reverend R. T.

Cross, of York, who had received them, without data, from Doane college, Crete, Nebraska. Drawings were made of the groups, and the matter was presented the same year to the Nebraska Academy of Science. Although diligent inquiry was made, nothing could be learned of their locality until the Reverend J. M. Bates, of Long Pine, informed the writer of the exact spot, which was visited as promptly as possible. The place was studied, a large amount of representative material collected, and photographs secured.

The mode of occurrence of these crystals seems most unusual and remarkable. In a bed of sand scarcely 3 feet thick, and so soft as to resemble the sand of the seashore, occur these crystals in numbers which can best be figured in tons. We dug them out with our bare hands. They were mostly single crystals, with numerous doublets, triplets, quadruplets, and multiplets. In other words, every form from solitary crystals to crowded bunches and perfect radiating concretions was obtained.

FIGURE 2.—*Sand Rock at Devil Hill, South Dakota.*

It is made up of sand crystals, as is revealed by certain hexagonal reflections and by an irregular prismatic structure developed on weathering.

It was a matter of especial interest in the field to note that at the bottom of the layer the bulk of these sand-lime crystals are solitary; one foot higher there is an evident doubling of the crystals, until within another foot they are in loosely crowded clusters; a little higher in closely crowded continuous clusters, pried out in blocks with difficulty; still higher they occur in closely crowded concretions in contact with one another, making nearly solid rock. A little higher this mineralizing process culminates in pipes, compound pipes, and solid rock composed wholly of crystals, but so solidified that their identity is lost, and is detected only by a certain reflection of light, which differentiates the otherwise invisible crystal units by showing glistening hexagonal sections. There could not have been a more gradual and beautiful transition, and all confined to a bed 6 or 8 feet in thickness. This is shown pictorially, though inadequately, in plates 13 and 14. Plate 14, figure 2, shows a

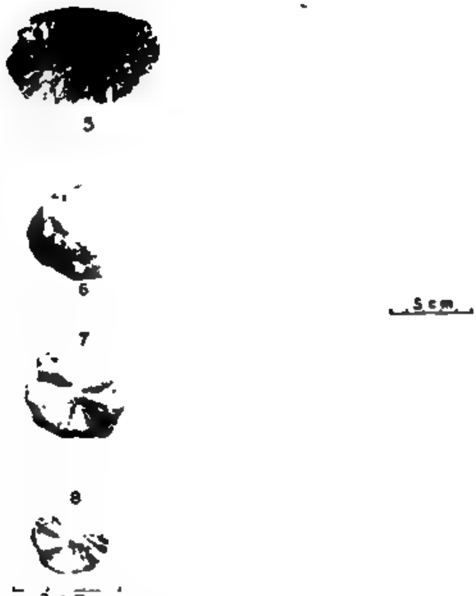


FIGURE 1.—GROUPS OF SAND CONCRETIONS
1 to 5 from Devil Hill; 6, 7, 8, from Nebraska

FIGURE 2.—CLUSTER OF SHEAF CRYSTALS (FIGURE 1) AND INTERPENETRATION TWINS (FIGURE 2)

SAND CONCRETIONS, SHEAF CRYSTALS, AND INTERPENETRATION TWINS

CLUSTER OF SAND CRYSTALS

portion of a great pipe on Devil Hill. Exposed for a distance of about 100 yards, this giant pipe is made up of sand crystals throughout its extent. Below may be seen innumerable small sand crystals, and in front a small pipe bristling with concretion crystals. The length of this remnant of a bed, which from its coarseness suggests a current deposit, is probably 500 yards in all, and it scarcely measures 20 yards at its widest point. In this band the material varies slightly, running from sand into gravel at times.

Overlying the crystal bed occurs some 25 feet of conspicuously cross-bedded and fairly coherent sand rock with ragged outline.

In the loose underlying crystal bed the sand is finely laminated, exhibiting colors as contrasting at times as black and white. The laminæ extend uninterruptedly through sand, sand crystals, concretions, and pipes. All the crystals show laminated lines. Planes of weakness follow the laminæ, and two effects are produced: first, the crystal, if exposed to atmospheric action, weathers more readily along certain planes, leaving others projecting; second, the crystals break more readily along certain lines (see plate 18, figures 1 to 9). This fracture is but a parting along the bedding plane, and is not to be confounded with cleavage, however like it it may appear. Although cleavage lines are present in the calcite, the sand, which is the predominating element, interferes with the cleavage throughout the mass, though many crystals imitate the calcite angle in fracture.

The most interesting single feature connected with these crystals seems to be the wonderful transition from the solitary crystals to the concretions, compound concretions or pipes, to the compound pipes and solid rock. This takes us back to the radiating concretions and compound concretions seen in our western counties, especially in Sioux county. It was this intimate relation between the sand-lime crystals and at least one type of concretionary structure which suggested the name concretion crystals. However, sand crystals or sand-lime crystals, as first proposed by the writer in 1893, seem to be simpler and more expressive terms, inasmuch as they explain the composition. These have subsequently been described by Penfield and Ford in the American Journal of Science of May, 1900.

Immersed in acid, the crystals are quickly broken down, the calcite being dissolved and the sand grains liberated.

To the observer in the field, it is interesting to note how these crystals vary from yard to yard in the same bed. Thus they pass through all gradations of size—from those scarcely a quarter of an inch (6 millimeters) long to those exceeding 15 inches (38 centimeters) in length, the average size, of which there are myriads, being 2½ to 3 inches (6 to 8 centimeters).

indistinct cleavage, is apparently etched, suggesting the probability of the lime being slowly leached away.

Figure 6, plate 18, is a camera lucida sketch of a cross-section of the crystal shown in figure 1, the calcite being indicated by stippling.

The preparation of such slides offers unusual difficulties because of the readiness with which the sand and silt grains part from the matrix in grinding the section.

Crystallographically these objects yield readily to inspection. They are plainly of the hexagonal system, but belong not to the holohedral, but to the hemihedral division. This is instantly apparent to the eye, for instead of presenting 6 similar faces they present three pairs of faces. Accordingly, similar edges and planes come to view with each turn of 120 degrees.

Of the six edges, three, lettered *s*, *s*, *s*, in plate 18, are visibly more obtuse and alternate with three which are less obtuse. Furthermore, the three edges and faces forming the more obtuse angles give brilliant reflections in sunlight, while the others are dull.

The sand crystal is simply a scalenohedron with many of its true characters interfered with and obscured by the sand inclusions. For instance, the zigzag is apparently lost. This is a condition far from phenomenal, for ordinary scalenohedra of calcite sometimes show no zigzag, save to the critical observer.

However, in a few sand crystals it seems to be barely discernible, and in others may be inferred from the fact that a given face does not lie in a continuous surface of curvature, but is warped slightly. If a crystal is held as shown in figure 2, plate 18, a portion, heavily shaded, remains in view after the rest of the face is revolved out of sight. A further revolution on the axis gives the result in figure 3, showing that they alternate. This points directly to the scalenohedron, the faces of which, if slightly curved vertically as well as laterally, would give precisely this result and would efface the zigzag. These are superficial signs, but they unmistakably indicate the scalenohedron.

Measurements confirm the eye determinations, but are subject to error from the fact that the faces are surfaces of double curvature and must be measured tangentially.

The crystal shown in figure 1, plate 18, when measured carefully, gave the following results, read in true angles, with supplement angles following in parentheses: (1) 113° (67°), (2) 128° (52°), (3) 116° (64°), (4) 125° (55°), (5) 114° (66°), (6) 126° (54°). The error in reading ordinarily runs from 2 to 6 or 8 degrees, being 2 in this case, as is shown by taking the sum of the supplement angles. All measurements show angles less obtuse, alternating with those more obtuse, at *s*, *s*, *s*.

This is shown graphically in figure 5, plate 18, which also shows the deviation of the faces from the straight lines of the included polygon. The rounded faces of the sand crystal correspond to the faces of the scalenohedron blended into 6 continuous surfaces easily mistaken for prismatic or pyramidal faces. The curved ends of these crystals offer no more difficulty than do the curved and warped faces. Almost every scalenohedron is modified, and its ends visibly rounded by the combination of one or more sets of rhombohedral planes. An attempt is made to show this graphically in figure 4, plate 18. These crystallographic signs are capable of exact interpretation by the crystallographer, to whom they must be consigned for further consideration, the writer contenting himself with this brief history of these remarkable new crystals and their apparent relation to certain concretionary forms.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 173-196, PL. 19 APRIL 18, 1901

A DEPOSITIONAL MEASURE OF UNCONFORMITY

BY CHARLES R. KEYES

(Read before the Society December 28, 1900)

CONTENTS

Introductory

An unconformity at the base of the Coal Measures in the upper Mississippi valley has long been known. In the writings of the early geological explorers are recorded observations showing that a physical break in the stratigraphic sequence was recognized at various localities between the coal-bearing strata and the underlying Carboniferous limestones. In most cases it was regarded as local discordance in sedimentation. Hall* appears to be the first to note the wide extent of the unconformity. Later, White † also emphasized its importance as a stratigraphic plane.

Of recent years much information has been obtained regarding the nature of this junction of the coal-bearing Middle Carboniferous strata and the formations on which they rest. The details of the unconformity plane have been so nicely worked out in so many localities that we have now a very good idea of its character, its real significance, and even of its relief features now so long buried.

This plane of unconformity has proved to be of wide extent. It is found stretching northward from the Ozarks beyond the south boundary of Minnesota. It bevels all the Lower Carboniferous formations, the Devonian, Silurian, Ordovician, and probably the Cambrian.

The plane represents undoubtedly an old land surface. Data regarding its depositional equivalent have been too incomplete to even suggest what it might include or where it might be represented; only recently ‡ has any indication been given as to the possible representative sediments. It is to this phase of the subject that attention is here called.

Carboniferous and its Subdivisions in the Mississippi Valley

Each of the states occupied by Coal Measures of the Western Interior basin has formed a general section of its formations that has been difficult to parallel with those of the adjoining states in any but an approximate way. Of late years the Carboniferous terranes of Iowa, Missouri, and Kansas have been brought into close accord. Those of Arkansas and Indian territory have also been subject to comparison; but no direct and exact correlation has been undertaken between the sections of the north and the south regions.

North of the Ozarks the classification of the median Carboniferous may be considered according to the following table: §

* Geology of Iowa, vol. i, 1858, p. 128.
† Geology of Iowa, vol. i, 1870, p. 226.
‡ Journal of Geology, vol. viii, 1900, p. 285.
§ American Geologist, vol. xxiii, 1899, p. 298.

Series.	Terrane.	Thickness in feet.
Oklahoman	Not here differentiated	
Missourian	Cottonwood limestone	10
	Atchison shales	500
	Forbes limestones	25
	Platte shales	105
	Plattsmouth limestones	30
	Lawrence shales	265
	Stanton limestones	35
	Parkville shales	75
	Iola limestones	30
	Thayer shales	50
	Bethany limestones	75
Des Moines	Marais des Cygnes shales	250
	Henrietta limestones	50
	Cherokee shales	200
	Hiatus	
Mississippian	Kaskaskia	275
	Saint Louis	300
	Augusta	250
	Chouteau	100

The Des Moines and Missourian series constitute what are called the Coal Measures.

In the Arkansas valley and Boston mountains the general section, as given by Branner,* is apparently totally different:

Series.	Terrane.	Thickness in feet.
Coal Measures	Poteau beds	3,500
	Productive beds	1,800
	Barren beds (Lower Coal Measures)	18,480
	Millstone grit	500
Mississippian	Boston group	780
	Batesville sandstone	200
	Fayetteville shale	300
	Wyman sandstone	10
	Boone chert	370
	Saint Joe marble	40

*Am. Jour. Sci. (4), vol. ii, 1896, p. 235.

Principal coal-bearing Formations

Extent and Character

Heretofore it has been generally conceded that the coal seams of the Coal Measures are limited to no particular horizon. This is only true in a very general way. Coal is found at many different stratigraphic levels, but what may be termed the productive formations are few in number.

The geological maps of the region give but faint idea of the actual disposition and relations of the coal seams. A consideration of the mine locations gives an equally vague conception of the horizons which furnish the chief fuel supplies. The general literature is so widely scattered and the references so disconnected that little help is to be had from this source.

Considering a coal horizon as a stratigraphic plane, along which coal has formed and which may be coal-yielding or not,* the extent of individual workable seams is extremely variable. There is no correspondence between thickness and areal extent. Some of the thickest beds are the most limited in their geographic distribution. The Versailles (Morgan county, Missouri) deposits,† which are upward of 60 feet in thickness, are less than a mile across. On the other hand, some of the thinner beds are found over a very wide area. The Mystic seam ‡ of southern Iowa and northern Missouri, though only about 3 feet thick, extends over many hundreds of square miles. So also the Grady seam of Arkansas and Indian territory has great areal extent. §

Productive Coal Series in the North

A short time ago the present coal output of each geological formation in Iowa, Missouri, and Kansas was the subject of special inquiry. In order to present the facts more clearly the supplies were tabulated according to percentages as follows:

Terrane Percentages of coal Production

	Iowa.	Missouri.	Kansas.
Missourian series:			
Atchison shales	0.2	....	6.0
Platte shales	....	....	0.13
Lawrence shales	....	....	....
Parkville shales	....	....	0.2
Thayer shales	....	....	....
Des Moines series:			
Marais des Cygnes shales	1 0	0.1	0.8
Henrietta formation	15.4	18.5	0.2
Cherokee shales	83.4	81.4	92.5

* Journal of Geology, vol. ii, 1894, p. 178.

† Eng. and Min. Jour., vol. xlix, 1900, p. 529.

‡ Iowa Geol. Survey, vol. ii, 1894, p. 408.

§ Proc. Am. Phil. Soc., vol. xxxvi, 1898, p. 330.

CORRELATED GENERAL SECTIONS OF THE CARBONIFEROUS IN WESTERN INTERIOR BASIN

It will be noted that nearly nine-tenths of the total coal output of the three states mentioned comes from the Cherokee division alone. This is about the proportion that the same terrane may be expected to furnish in the future. If anything, the Cherokee percentage will increase rather than diminish, as the Henrietta coal comes from a single seam, which lies very near the base of the formation. Hence, if we care to take a few feet of this terrane and add it to the Cherokee, we would have practically 98 per cent of the entire Trans-Mississippian output of coal north of Arkansas coming from the lowermost member of the Coal Measures—the Cherokee shales.

The maximum thickness of the Cherokee shales may be taken to be about 300 feet. From this measurement the terrane tapers out eastwardly to a feather-edge. If the total thickness of the Coal Measures of the region (Des Moines and Missourian series) north of Arkansas be taken at 2,000 feet, the basal one-seventh furnished 98 per cent of the whole coal supply, present and future.

PRODUCTIVE COAL SERIES IN THE SOUTH

In considering the coal output of the Arkansas valley the chief producing strata are, according to Branner, not at the base of the Coal Measures, but some 18,000 feet above. In western Arkansas this productive terrane of Branner appears to include both the lower and eastern coal-bearing divisions of Winslow,* the intermediate barren division, of indefinite delimitation, and the chief coals of the upper or western coal-bearing division. The highest coal horizons of the state were apparently unknown at the time the report was made; at least their real stratigraphical position was not appreciated.

While some thin coals are known at other levels, the whole coal supply of Arkansas and Indian territory south of the Arkansas river comes from a terrane higher above the Kaskaskia beds of the Mississippian than the whole Carboniferous section of Missouri and Kansas. In both Missouri and Arkansas the correlation of the Kaskaskia beds has been determined with accuracy, so that their exact position is known.

Geological Sections of the Region

GENERAL CONSIDERATIONS

In the accompanying diagram (plate 19) are arranged the general geological sections of the Trans-Mississippian Coal Measures as repre-

*Arkansas Geol. Survey, Ann. Rept. 1888, vol. iii, p. 22.

sented in the several states occupied by this great coal field. As indicating more clearly the various stratigraphic relationships, the sections as given by the chief writers on the subject in each state have been selected. In this way also the literature in general is more fully understood in its bearing upon the special theme here presented.

Number I is the general section of western Missouri, and includes the typical Missourian series* and the Des Moines† series as there represented. In its main features the arrangement holds good for Iowa,‡ and also Kansas.§ The horizon of the Bethany limestone, the base of the Missourian series, is indicated; also the horizon of the Plattsmouth limestone, for reasons hereafter mentioned. The top of the same series, the Cottonwood limestone, is likewise a noteworthy horizon.

In number II is given the section of southern Kansas, in accordance with the observations of Adams and Haworth.‖ Some of the terranes are here thicker than farther north.

What are called the Pawhuska (number III), the Sapula (number IV), and the Poteau Mountain (number V) sections are those for northern, central, and southeastern Indian territory as generalized by Drake.¶ Of the two Arkansas sections, the one for the western part of the state (number VI) is that of Winslow, as published by Stevenson,** while the more general section (number VII) is that of Branner.††

The course of these sections may be considered as a semi-circle extending around the western part of the northern Ozarks. It coincides with the lowland belt flanking the great elevation between the Arkansas and Missouri rivers.

IOWA SECTION

The details of the northern end of the general cross-section are to be found in the reports of the Iowa Geological Survey.‡‡ The Iowa section differs in no essential features from that given for Missouri. The subdivisions of the Des Moines series are perhaps not quite so well marked as in southwest Missouri, and the Iola limestone is missing, having thinned out before reaching the northern boundary of the last-named state. The formations, on the whole, are much thinner than farther

* American Geologist, vol. xxiii, 1899, p. 298.
† Proc. Iowa Acad. Sci., vol. iv, 1897, p. 22.
‡ American Geologist, vol. xxi, 1898, p. 346.
§ Eng. and Mining Jour., vol. lxi, 1898, p. 253.
‖ Univ. Geol. Survey Kansas, vol. iii, 1898, pl. i.
¶ Proc. Amer. Philos. Soc., vol. xxxvi, 1898, p. 372.
** Trans. New York Acad. Sci., vol. xiv, 1895, p. 51.
†† Am. Jour. Sci. (4), vol. ii, 1896, p. 235.
‡‡ Iowa Geol. Survey, vol. ii, 1890.

south. The maximum thickness of the Coal Measures is about 1,600 feet, in the extreme southwest corner of the state.

MISSOURI SECTION

The typical section of Missouri has already been given in connection with the general statement regarding the Carboniferous and its subdivisions in the Mississippi valley. Within the state limits, however, the full sequence of the Missourian is not represented, the extreme upper part of the series not being found so far to the east. The maximum thickness of the Coal Measures is the same as for Iowa, and is found in the extreme northwestern corner of the state.

In southwestern Missouri the sandstone and conglomerate beds lying at the base of the Coal Measures, and called the Graydon sandstone, in Greene county,* for example, have been referred to the Des Moines series.

In this part of Missouri the Coal Measures rest directly upon the Augusta limestone. Over a considerable part of the region the latter also forms the surface rock. Remnants of the Saint Louis limestone with characteristic fossils have been observed. On the southern border of the state the Kaskaskia beds have been recognized.†

KANSAS SECTION

In the extreme southern part of the state the Missourian series is considerably thicker than it is along the Missouri river. A notable feature is the thickening of the limestones toward the west and the introduction of new limestone beds.

The great limestone formations are slightly tilted to the northwest, and a succession of marked eastward-facing escarpments are prominent features of the topography of the region. These escarpments continue on southward well into Indian territory.

INDIAN TERRITORY SECTION

The three general sections of the Coal Measures given by Drake ‡ indicate a very great thickening to the southward. In his subdivision of the Carboniferous above the Mississippian he recognizes (1) the Lower Coal Measures, (2) the Upper Coal Measures, composed of the Cavaniol and Poteau groups, and (3) the Permian. From his notes alone it would be difficult to compare these sections with the Kansas section. Personal observations in the field enable the two districts to be paralleled, so that

* Missouri Geol. Survey, vol. xii, 1898, p. 124.
† American Geologist, vol. xvi, 1895, p. 86.
‡ Proc. Am. Philos. Soc., vol. xxxvi, 1898, p. 372.

if Drake's tracings in the field are correct we are able to tell quite closely the relationships which the southeastern sections bear to those north of the territory.

Drake's correlation is that the Lower Coal Measures of Indian territory are (presumably) equivalent to the formation of the same title farther north. The Cavaniol (Kavanaugh) is paralleled with the Missourian up to the Atchison (Waubaunsee) shales, while the Poteau is made the representative of the latter and the Cottonwood terrane. The exact grounds for this correlation are not clear, though it is inferred to be chiefly the fossils.

There are cogent reasons for believing that all of the Indian Territory beds are much lower in the stratigraphic scale than Drake has supposed. It has already been shown * that Smith's conclusions † "that Poteau Mountain beds were high up in the Coal Measures," probably in part Permian, are not necessarily correct. It was further stated that his detailed evidence indicated rather that the beds in question were much lower, possibly as far down as the horizon of the Des Moines series. The data presented by Drake, and partly corroborated by personal examination, point to the correctness of the suggestion.

Where the Cavaniol group, as indicated on Drake's map, is extended into Kansas, it falls wholly within the boundaries of the Des Moines series. The eastern limits are the same, if the basal sandstone is considered by itself. The upper or western boundary coincides with the lowermost of the Bethany limestones. If the Poteau is rightly traced, it corresponds, in Indian territory, to the Missourian series of Kansas up as far as possibly the Plattsmouth (Oread) limestone, but certainly not higher. The details of the northern extension of Drake's Poteau are obscure, and it is just possible that the limit is more nearly that of the Iola limestone.

If this is the correct interpretation, and it appears that it is, Drake's Cavaniol group is almost the exact equivalent of the Des Moines series, minus the basal sandstone of the more northern localities, while his Poteau group is to be paralleled with the Missourian series below the Plattsmouth limestone. The basal sandstone, placed by Drake in his Lower Coal Measures, would appear to belong, toward the north, to what has been regarded as a part of the Des Moines series, and to the south to a lower horizon than any of that series north of the Kansas line.

In the eastern part of the territory, south of the Arkansas river, the

* Journal of Geology, vol. vi, 1898, p. 356.

† Proc. Am. Philos. Soc., vol. xxxv, 1896, pp. 213–285.

coal fields have been extensively developed and the coal seams traced for long distances. On account of the wide extent of the coal beds the various sections in this part of the territory are readily compared with one another and with those of the neighboring state on the east. There are three notable seams in the Choctaw field: the Grady (Huntington, of Arkansas), the McAlester, and the Mayberry. Drake's Cavaniol group embraces the strata between the Grady and Mayberry coals. The maximum distance between these two horizons is estimated by Drake to be 5,000 feet, though in his general section it is only about 1,700 feet.

When we come to compare Chance's section * with that made by Drake, we find that he places the distance between the two coals at a little over 8,000 feet, which is certainly excessive, as has already been suggested.† With the exception of the 1,200 feet of shale above the Mayberry or Kavanaugh coal and 200 feet beneath the Grady coal, the whole of the Chance section would belong to the Cavaniol group.

Stevenson ‡ has paralleled the section made by Chance with Winslow's section of the Coal Measures of western Arkansas in his yet unprinted report. It seems impossible to reconcile this attempt with the known facts. Winslow states § clearly that the Huntington (Grady) coal is near the base of his Poteau stage. This being the case, his six other stages are all below the base of Chance's section. This feature is shown in plate 19.

In this connection it may be said that Drake's Poteau group is not the Poteau of the Arkansas geologists. Winslow's Poteau stage, and, presumably, also Branner's, extends upward from the Grady coal horizon to the beds at the top of Poteau mountain, an horizon near the Mayberry coal. The Poteau formation of Arkansas is, therefore, practically the exact equivalent of Drake's Cavaniol group, while the latter's Poteau lies wholly above the Poteau of Arkansas.

In regard to the lower part of the section, it may be stated that what Drake calls the Lower Coal Measures is below the Lower Coal Measures of Missouri and Kansas. The Lower Coal Measures of Indian territory, which are not the Lower Coal Measures of the region farther north, are very thin at the north and are there merged with the basal standstone of the Des Moines series. Southward they rapidly increase in thickness until, beyond the Arkansas river, they have an ascribed measurement of more than 2,000 feet. In Chance's section of the Choctaw coal field

* Trans. Am. Inst. Min. Eng., vol. xviii, 1890, p. 658.
† Journal of Geology, vol. vi, 1898, p. 358.
‡ Trans. New York Acad. Sci., vol. xiv, 1895, p. 52.
§ Ibid., p. 51.

only the lower 200 feet out of the entire 10,000 feet appear to belong to the Lower Coal Measures as given by Drake.

ARKANSAS SECTION

The most complete section of the Coal Measures of Arkansas is that constructed by Winslow for his unpublished report on the coals of the state. The section has been, however, published by Stevenson.* Comparing his earlier section † with this one, it is assumed that the lower or eastern coal-bearing division corresponds to the Spadra stage, the intermediate or barren division to the Sebastian stage, and the upper or western coal-bearing division essentially to the Poteau.

As the positions of the higher coals in the Poteau were not well understood in Arkansas, it seems probable that the Grady or Huntington coal at the base of the Poteau and the lower coals occurring in the Spadra stage were included in Branner's productive beds.

The Spadra formation is best developed in central Arkansas and is believed to thin out westward, failing altogether before the limits of the state are reached. Beneath this terrane Branner considers that there are still about 18,000 feet of Coal Measures represented in the state.

In this connection it must be again stated that the Poteau beds of the Arkansas geologists do not form the Poteau group of Indian territory, as designated by Drake, but correspond to the latter's Cavaniol group.

Correlation of the General Sections

STRATIGRAPHIC RELATIONSHIPS

The detailed work done during the past decade in the various parts of the Trans-Mississippian coal fields has enabled satisfactory correlations to be made without falling back upon the fossils. Various horizons have been traced in the field, so that every portion of the area occupied by the Coal Measures may now be considered as being very closely connected.

If these correlations have been correctly carried out, it would appear that, taking the section of the Missouri river as a standard, the serial subdivisions are readily followed around the Ozarks occupying southern Missouri and northern Arkansas.

According to the accumulated stratigraphic evidence, there begins south of the Kansas boundary a formation having no representative terrane to the north. This formation rapidly gets thicker and thicker southward and eastward until, if Branner's estimates are correct, it attains

* Trans. New York Acad. Sci., vol. xiv, 1895, p. 51.
† Arkansas Geol. Survey, Ann. Rept., 1888, vol. iii.

the enormous vertical measurement of 20,000 feet. This great terrane, composed almost entirely of shales and sandstones, lies entirely below the basal horizon of the Des Moines series (Lower Coal Measures) of Missouri, but is above the Kaskaskia beds.

The Des Moines series of Missouri appears to have its almost exact equivalent in Indian territory in the Cavaniol group and in Arkansas in the Poteau division.

The Missourian series, up, perhaps, as far as the Plattsmouth limestone, corresponds closely with the Poteau division of Indian territory.

The so-called Permian of Indian territory seems to be the upper part of the Missourian series. The strata above the horizon of the Cottonwood limestone of Kansas are not known definitely to occur within the limits of Indian territory.

FAUNAL COMPARISONS

As yet no complete faunal studies have been made with the special object in view of careful correlation of the various formations throughout the coal field. What suggestions the fossils have offered are, however, not without interest. This is particularly so when the north and south parts of the field are compared.

The most important published data on the fossils of the Arkansas Coal Measures are by Smith.* This author is of the opinion that the Lower Coal Measures and Upper Coal Measures of Arkansas are to be paralleled with the similarly named formations farther north. He concludes that—

> "There is not sufficient reason for classing the Poteau Mountain beds with the Permian, but their fauna, as well as stratigraphic position, place them very high in the Coal Measures, since they are like the fauna and position of the Mississippi Valley Upper Coal Measures. These beds derive an additional interest from the fact that on Poteau mountain 1,000 feet of shale, in which no fossils were sought for, lie above the thin layer from which the entire collection was taken."

The correctness of this conclusion has been questioned.† A careful comparison of the species of fossils that are considered by Smith to belong to the Upper Coal Measures with those from the Upper and Lower Coal Measures of other parts of the Western Interior basin brings out the fact that the Arkansas fauna not only does not necessarily indicate for the zone containing it a "very high" position in the more northern Upper Coal Measures, but that it may be and probably is very low. Judging from the fauna alone and as a whole, according to the paleontological standard of its nearest and most closely related district—

* Proc. Am. Philos. Soc., vol. xxxv, 1896, pp. 213-285.

† Journal of Geology, vol. vi, 1898, pp. 356-365.

the Missouri-Kansas province, with which it is properly compared—the indications are that the age of the strata yielding it is not of the "Upper Coal Measures" at all, but of the "lower division"—that is, of the Des Moines series of the more northern localities.

All of the Arkansas species, with very few exceptions, are, in Iowa, Missouri, and Kansas, the most widely distributed forms. Most of them range from the base to the top of the Des Moines series, and continue upward. In the lower series the marine beds are almost wholly absent, only a few thin limestones being present in the whole succession. Nevertheless, the same species, which are found in Arkansas, occur abundantly not only in the thin limestone layers, which are rarely more than a few inches in thickness, but also in the calcareous shales, and in less numbers even in the bituminous shales.

Of the corals listed from Arkansas only one form has a range that is unusually "high" in the northern succession; all of the others start almost from the very base of the series. The crinoids and bryozoans are all common in the Lower Coal Measures. All fourteen species of brachiopods are of very frequent occurrence in the Lower Coal division, many commencing down in the Mississippian. One possible exception is *Terebratula bovidens*, which at present appears to be absent from some of the lower Des Moines beds. Of the lamellibranchs, all twenty-two species are the most characteristic forms in the very base of the Missourian; one-half of the number are found lower down, and no less than seven are typical Des Moines forms, in fact having an optimum habitat not in the marine beds, but in the bituminous shales. The seven species of glossophora that are enumerated are the most abundant forms of the Lower Coal Measures throughout the northern district, and they are preeminently the characteristic fossils of the black shales everywhere. Among the ten cephalopods named, no less than five are of common occurrence in the Des Moines beds, and not infrequently they are found in the black shales; the other five, so far as known, range low in the Missourian.

If the faunal evidence as recently presented is to be relied on at all, it would appear that there are no grounds for believing that there are necessarily present in the deposits of the Arkansas Valley region any strata higher than perhaps the middle of the Missourian series of Missouri and Kansas.

The fossils listed by Drake * as coming from the Cavaniol group would hardly be considered as coming from the horizons farther north, called the Upper Coal Measures (Missourian series). The species are all very

* Proc. Am. Philos. Soc., vol. xxxvi, 1898, p. 393.

common ones, and all have a very great vertical range, so that there they are by no means determinative. If the lists were examined without reference to the horizons ascribed to them, their stratigraphic positions would certainly be pronounced the same as that for the forms from the Des Moines series of Missouri.

Tho fossils enumerated by the same author as indicating the top of the Missourian of Kansas must certainly be paralleled with the base of that formation.

FLORAL PARALLELISM

The earlier references* to the coal floras of Arkansas throw little light upon the stratigraphic position of the plant beds. Lesquereaux † in his Coal Flora describes a number of species from the Arkansas region.

Smith ‡ alludes to the unpublished monograph by Fairchild and White on the "Fossil Flora of the Coal Measures of Arkansas," in which it is said to be stated that all the published plant remains are regarded as belonging to the upper or productive Coal Measures—of Pennsylvania presumably.

In a paper read before the Geological Society of Washington § by David White it is reported that—

> "The flora of the Grady, or Hartshorn, coal he finds to indicate a reference to the 'lower coal-bearing division' of Winslow, or the basal portion of the Upper Coal Measures of Branner and Smith, in Arkansas, and a stage near the base of the Alleghany series of the Pennsylvania-Ohio bituminous regions. The plants of the McAlester coal, about 1,500 feet above the Grady coal, assure a correlation with the upper coal-bearing division of Winslow, in Arkansas, a stage, perhaps, near the Lane [Parkville] shales in the lower half of the Missourian in Kansas, probably below the Pittsburg coal, in Pennsylvania, or near coals F or G of the northern Anthracite field. Vegetable remains collected by Messrs. Taff and Richardson from a horizon about 2,000 feet above the McAlester coal constitute a distinctly Coal Measures flora, without any characteristic Permian species."

The principal fact brought out by the testament of the fossil plants is that the coals of western Arkansas are well up in the general section of the Coal Measures, at a horizon that would be somewhere in the Upper Coal Measures of the Appalachian region.

The plants of the Clinton region in Missouri, according to White,‖

*Arkansas Geol. Survey, Second Ann. Rept., 1860, p. 309.
† Pennsylvania Geol. Survey, vol. P, 1884, p. 55.
‡ Journal of Geology, vol. II, 1894, p. 195.
§ Science, n. s., vol. vii, 1898, p. 612.
‖ U. S. Geol. Survey, monog. xxxvii, 1900.

indicate a similar position, although there the plant horizons are within 100 feet of the Mississippian series.

Table of Terranes in Western Interior Coal Field

	General.	Missouri-Kansas.	Indian territory.	Arkansas.
Carboniferous.	OKLAHOMAN SERIES.			
	MISSOURIAN SERIES ...	Cottonwood. Atchison. Forbes. Platte. Plattsmouth. Lawrence. Stanton. Parkville. Iola. Thayer. Bethany.	Poteau.	Wanting.
	DES MOINES SERIES...	Marais des Cygnes. Henrietta. Cherokee.	Cavaniol.	Poteau.
	ARKANSAN SERIES	(Hiatus.)	Sebastian. ? ? Booneville. ?	Sebastian. Spadra. Norristown. Booneville. Appleton. Danville. Millstone grit.
	MISSISSIPPIAN SERIES..	Kaskaskia. Saint Louis. Augusta. Chouteau.	Boston group. Boone. ?	Boston group. Boone. Saint Joe.

RELATIONS TO TEXAS SECTION

The close approximation in the equivalency of the Coal Measures of Missouri and Kansas and those of Arkansas and Indian territory enables the Texas Carboniferous to be more clearly understood. As yet, the Coal Measures of Texas are only provisionally subdivided. However, the Cisco and Canyon divisions of Cummins* appear to very nearly represent the Missourian series of the more northern region.

* Texas Geol. Survey, Second Ann. Rept., 1891, p. 361.

This leaves the Strawn, Milsap, and perhaps a part of the Bend division equivalent to the Des Moines and Arkansan series. The great thickness of these Texas divisions seems to give support to this interpretation. The revision of Drake's correlation * of the Indian Territory Coal Measures with those of Kansas corroborates this opinion.

CORRELATION OF WESTERN INTERIOR AND ALLEGHANY SECTION

Without more exact stratigraphic knowledge than at present exists regarding the vast intervening area, all attempts at correlation of the sections of the two great fields can only be considered as merely broad approximations; yet the comparison is not without interest and value. The principal data has recently been gathered from the plant remains.

If we follow the suggestions of David White, the Des Moines series in western Missouri is to be regarded as representing the Alleghany series of Pennsylvania.† In the consideration of the fossil plants of the McAlester coal field by the same author ‡ three widely separated horizons are represented. The middle one, the McAlester coal, is regarded as belonging to the level of the lower part of the Missourian series, and as probably older than the Pittsburg coal, the base of the Monongahela series of Pennsylvania. The lower horizon, the Grady coal, is placed in the Alleghany series, and "probably in the lower half."

According to the evidence now presented both the McAlester and Grady coals are in the Des Moines series.

UNCONFORMITY AT BASE OF COAL MEASURES

EXTENT AND NATURE

West of the Mississippi river the unconformity at the base of the Coal Measures is known to extend in a north-and-south direction a distance of more than 500 miles. This is the distance from about the north boundary of Arkansas to the southern limit of Minnesota.

From the Mississippi river the rocks have a general dip to the westward. Over a considerable belt of country west of the great river the juncture of the Coal Measures with the underlying formations is visible. The width of this belt is from 100 to 200 miles. How much farther westward it extends is not known, since the horizon soon is covered too deeply by the overlying strata.

---

* Proc. Am. Philos. Soc., vol. xxxvi, 1897, p. 388.

† U. S. Geol. Survey, monog. xxxvii, 1899.

‡ U. S. Geol. Survey, Nineteenth Ann. Rept., pt. iii, 1900, p. 457.

On the highest parts of the Ozark dome in Missouri the Coal Measures are still found resting on the uneven, channeled surface of the Lower Carboniferous. South of the southern boundary of Missouri there is no evidence that any break in sedimentation occurs between the Coal Measures and Lower Carboniferous formations.

How far east of the Mississippi river the unconformable relations exist is not now known. However, along the line where the basal plane of Coal Measures dips beneath the eastward sloping strata the unconformity is everywhere observable.

The plane of unconformity at the base of the Coal Measures represents clearly an old land surface that was subjected to erosion for a period long enough for the tilted strata to be completely beveled off from the Kaskaskia limestone down to the Cambrian sandstones. During the interval between the deposition of the last of the Lower Carboniferous formations of the region and the Coal Measures of the Upper Mississippi valley enormous denudation took place. Heretofore the extent of this erosion has been little appreciated.

TOPOGRAPHY OF THE OLD LAND SURFACE

The evidence already at hand indicates plainly that the surface on which the Coal Measures of the upper Mississippi valley were laid down was quite diversified. There were hills and vales, differing in elevation by several hundreds of feet. Some of these have been especially noted by Bain * and other members of the Iowa Geological Survey. There were broad drainage basins and deep narrow gorges.† In some localities even traces of extensive dendritic stream systems are discernible. Some of the most notable of these are described by Shepard ‡ in southwest Missouri.

If we wish to get a general conception of what this old surface relief actually was, we gather something of its real character by comparing it with the relief now existing. The topographic contrasts are certainly nearly as marked in the old Carboniferous as they are today over the same area.

SIGNIFICANCE OF THE UNCONFORMITY

The phenomenon under special consideration has been generally regarded as local in its nature—the same as many unconformities occurring

* Iowa Geol. Survey, vol. i, 1893, p. 174.
† Missouri Geol. Survey, vol. i, 1891, p. 167.
‡ Missouri Geol. Survey, vol. xii, 1898, p. 127.

at many horizons in the Coal Measures. That it signifies an important sequence of events has never been sufficiently emphasized. That the horizon is really a great hiatus has never been fully considered. That the interval represents a period in the history of the region of much longer duration than it took to form all the Coal Measures above it is a phase of the subject never before suggested.

It has lately been shown * that the present Ozark uplift is of comparative recent date—that is, not older than Tertiary. In considering the region as it was in Carboniferous times, the dome must be neglected and the area regarded as forming a lowland plain, the same as the rest of the region was known to be. This is further indicated by the fact that on the highest parts of the dome remnants of the Coal Measures are still found on the beveled edges of the older strata.

The oscillation of the Carboniferous shoreline in the upper Mississippi valley has already been described in detail.† The evidence goes to show that immediately after the Kaskaskia beds were laid down land existed north of the present Arkansas-Missouri boundary. This was a region of profound and prolonged denudation. South of the line mentioned sedimentation continued. The land waste from the northern district was carried into the southern waters.

The northern area, after the close of the early Carboniferous period, being an area of denudation, suggests an area to which the waste was carried and deposited. There is also suggested a depositional measurement of the erosional period.

Basal Series of Coal Measures in Arkansas

Thickness and General Character

Heretofore the Coal Measures of Arkansas have been regarded as anomalous. They present an enormous development as compared with the Coal Measures of other parts of the Mississippi valley and even of other portions of North America.

The thickness of the Coal Measures of the Arkansas valley, as estimated by Branner,‡ is nearly 24,000 feet. If present correlations be correct, the highest of these beds in Arkansas are not much, if any, above the horizon of the Bethany limestone of Missouri and Kansas. For the deposition of such an enormous sequence there must have existed ex-

* Missouri Geol. Survey, vol. viii, 1895, p. 351.
† Iowa Geol. Survey, vol. i, 1893, p. 118.
‡ Am. Jour. Sci. (4), vol ii, 1896, p. 235.

ceptional conditions. The great development of the Coal Measures in Arkansas is not widespread, but is confined to a comparatively limited area.

The noteworthy feature in the lithology of the Arkansas Coal Measures is their make-up of shales and sandstones, with an almost total absence of marked limestones. While this characteristic is remarkable through such an extensive succession, it points clearly to attendant physical conditions that are unmistakable, and that are now known to be in perfect harmony with the historical record of other parts of the region.

RELATIONS TO THE UNDERLYING MISSISSIPPIAN

The Lower Carboniferous formations are well understood in Arkansas. It is now known that the Boone cherts are essentially the Augusta formation of Missouri, and are continuous with that formation as developed in the southwestern part of the last-mentioned state. The widely recognized Batesville sandstone has been proved by Weller,* without much doubt, to be the equivalent of the Aux Vases sandstone of the Mississippi River region, the basal member of the Kaskaskia formation.

It is now generally agreed that the Boston group of northwestern Arkansas is the equivalent of the Kaskaskia limestone and Chester shales of the Mississippi river. Typical Kaskaskia fossils have been found in the shales of this group in the extreme northwestern corner of the state † and in the adjoining parts of Missouri.

The exact line of demarkation between the Lower Carboniferous and the Coal Measures has not been drawn in Arkansas. In the northwestern part of the state, Simmons,‡ without giving any reasons or data for deducing his conclusions, has regarded a thin, shaly limestone as the topmost number of the Mississippian. As the shales beneath the Kessler limestone carry thin coal seams, with an abundant flora, it may be that these, as well as the Kessler, may eventually prove to belong more properly with Coal Measures.

In this section it is at present uncertain just where the separating line between the Mississippian and Coal Measures should be placed. In the Boston mountains the stratigraphic succession is apparently unbroken from the Boone chert (Augusta) upward. Above the Batesville sandstone the undoubted Kaskaskia beds upward assume more and more the character of the Coal Measures, and into the latter the former

* Trans. New York Acad. Sci., vol. xvi, 1897, p. 251.

† American Geologist, vol. xvi, 1895, pp. 86–91.

‡ Arkansas Geol. Survey, Ann. Rept., vol. iv, 1888, p. 104.

appear to gradually merge. Nowhere in this region has there been noted any evidence of unconformable relationships, nor do any of the Arkansas geologists mention any facts indicating that a stratigraphic break might exist.

The zone of uncertain age is, however, thin, and the basal line of the Arkansas Coal Measures may be regarded as determined within very narrow limits.

All evidence at hand goes to show clearly that in Arkansas sedimentation was continuous during the Carboniferous; that enormous deposits were laid down during the period, and that while the beds were being formed there was in the region no marked orogenic movement.

SUPERIOR DELIMITATION OF BASAL SERIES

From the north down to the Arkansas line the Des Moines series of the Coal Measures is well demarcated below—by the unconformity separating it from all older rocks. Its lowest horizon at this point appears to coincide with the horizon taken as the base of the Cavaniol group of Indian territory, as traced in detail by Drake. The Cavaniol, in turn, is correlated in the main with the upper or western coal-bearing division or Poteau of Arkansas, which also includes part of the productive Coal Measures.

The base of the Cavaniol group is now taken to be the Grady coal. This horizon may be considered as limiting above the great Arkansan series of the Coal Measures. The latter is therefore entirely below the horizon of any part of the Des Moines series as represented in Missouri and farther north.

HOMOGENEITY OF THE ARKANSAN SERIES

Notwithstanding its tremendous thickness in central Arkansas, the unusual development may be considered as comparatively local in nature. From bottom to top it appears to represent practically the same uninterrupted deposition.

Although divisible into a number of subordinate formations, it is throughout essentially a compact, homogenous geological unit. Hence from every standpoint it is thus best considered.

SUBDIVISIONS

The Arkansas geologists have not yet had opportunity to publish in detail their latest opinions regarding the formations or terranes which

they consider as making up the Coal Measures of the state. Winslow's section, however, is not without interest, and is given below:

Sebastian stage.	Booneville stage.
Spadra stage.	Appleton stage.
Norristown stage.	Danville stage.

RELATIONS OF ARKANSAN SERIES TO GREAT UNCONFORMITY

CORRELATION

From the foregoing it is seen that the Lower Carboniferous or Mississippian series, with its minor divisions, is well defined in northern Arkansas. The Kaskaskia terrane is easily identified, passing upward south of the Boston ridge into the Coal Measures.

FIGURE 1.—*Relations of Arkansan Series (black) to the other Carboniferous Series.*

The basal horizon of the lowest Coal Measures of Missouri, or Des Moines series, is believed to extend southward, and to the south of the Arkansas river to coincide approximately with the Grady coal horizon, or the base of the Cavaniol.

With the base of the Des Moines series of Missouri thus located in Arkansas, and the top of the Lower Carboniferous well defined, it leaves in the south an immense thickness of nearly 18,000 feet of sediments that are in the north wholly unrepresented by deposits. The 18,000 feet of sediments were manifestly laid down during the period represented by the stratigraphic break at the base of the northern Coal Measures.

DEPOSITIONAL MEASURE OF EROSION PERIOD

The magnitude of the hiatus at the base of the Coal Measures of Iowa, Missouri, and Kansas is readily appreciated when we find a place where

sedimentation uninterrupted attained a vertical measurement of 18,000 feet. The period of which there is no measurable record in one part of the region finds in an adjoining district sediments of greater significance than all the Coal Measures immediately above the break.

Here, then, is a case in which on the one side of an old shoreline is the land area that suffered profound denudation and on the other the water area in which sedimentation was carried to a prodigious extent. In point of time one is the exact equivalent of the other.

RÔLE OF THE OZARK UPLIFT

Heretofore in the considerations of Paleozoic stratigraphy in the Mississippi basin the Ozark dome has been made much of. This has been particularly noticeable in the case of the Coal Measures. The Ozark isle

FIGURE 2.—*Carboniferous Deposition in the Western Interior Basin (black wanting).*

has been a favorite theme to dwell on in explaining the sedimentation of the region.

It has been recently shown in a conclusive manner that the Ozark dome can not be taken into account in considering the deposition of the Coal Measures of the region. The present Ozark uplift is Tertiary in age. During the deposition of Lower Carboniferous the area occupied by the dome was sea, in which limestone was being deposited. When the Arkansan series was laid down the Missouri area was a land surface, but a coastal plain of moderate relief, which later was covered by water.

The dome did not rise as the "Ozark isle" until long after Carboniferous sedimentation had ceased.

THICKNESS OF THE CARBONIFEROUS

The thickness of the Coal Measures of the Mississippi valley is greater than anywhere else in the United States. In two east-and-west cross-sections, one on the north side of the Ozark dome and the other through the Arkansas valley, are contrasted the Carboniferous series which present about the following measurements:

	Northern section.	Southern section.
Oklahoman	1,500	1,500
Missourian	2,000	1,500
Des Moines	500	3,500
Arkansan	Wanting.	20,000
Mississippian	1,000	1,500

Conditions under which Arkansan Series was Deposited

The deposition of such an enormous mass of sediments as is found making up the Coal Measures of the Arkansas valley must have required some unusual conditions. Branner * has attempted to explain the circumstance as follows:

"If we inquire into the reason for the great thickness of Coal Measure sediment in the Arkansas valley, I believe it to be found in the drainage of the continent during Carboniferous times. The rocks of this series in Arkansas contain occasional marine fossils, and these marine beds alternate with brackish or fresh water beds, whose fossils are mostly ferns and such like land or marsh plants. This part of the continent was, therefore, probably not much above tide level. The drainage from near the Catskill mountains in New York flowed south and west. The eastern limit of the basin was somewhere near the Archean belt, extending from New England to central Alabama. This Appalachian watershed crossed the present channel of the Mississippi from central Alabama to the Ouachita uplift or to a watershed still farther south and now entirely obliterated and buried in northern Louisiana. In any case the drainage flowed westward through what is now the Arkansas valley between the Ozark island on the north and the Arkansas island on the south."

The chief objection to this view is that we now know that the northern Ozark isle and the Ouachita part of the uplift did not exist as the pres-

* Am. Jour. Sci. (4), vol. ii, 1896, p. 236.

ent mountainous uplifts in Carboniferous times. North of the Missouri-Arkansas line the region was land, to be sure, after the Lower Carboniferous marine beds had been laid down. South of that line sedimentation continued in deepening waters. The sediments were carried from the north or northeast and dumped off the shore, rapidly building the latter outward.

There may have been a great land area in northern Louisiana, and probably was. If so, what is now the Arkansas River valley was a broad, deep estuary opening out to the west, and the sediments came in from both sides, as well as from the head toward the east. The conditions were then similar to those presented now by the lower Mississippi plain. Only the great embayment opened to the west instead of to the south.

The present Arkansas valley, however, has probably been formed through erosion entirely since Tertiary times and by a system of drainage in no way dependent upon the Carboniferous drainage. When the great uplift of Missouri and Arkansas rose, the northern part embracing the so-called Ozark isle and the southern part comprising the Ouachita mountains, were made up of resistant limestones, yielded less quickly to erosion than the central soft shales, and the Arkansas river, which happened, in the old peneplain, to traverse the central part of the uplifted area was able to cut its way down as fast as the region rose, and was thus able to maintain its old course. The present uplift, which is due to one general movement, is now apparently divided into two elevated regions separated by a broad valley.

Recapitulation

Summing up, it may be said that the facts set forth in the foregoing account indicate that:

(1) The Coal Measures of the Western Interior basin find a greater development than in any other locality known in America, no less than three great series being recognizable, each of which is as important as the combined series as usually developed in Pennsylvania.

(2) The Lower Coal Measures of the upper Mississippi valley, though resting in great part directly on the Lower Carboniferous, are in reality high up in the Carboniferous—in the upper half.

(3) The hiatus at the base of the Coal Measures in the upper Mississippi valley has in the south a depositional equivalent, the importance of which is greater than the whole of the Coal Measures to the north.

(4) The present Ozark uplift had no effect in determining the deposition of the Coal Measures.

(5) The Poteau group of Arkansas, the Cavaniol of Indian territory (containing the Grady and McAlester coals) are practically coextensive with the Des Moines series farther north (Lower Coal Measures).

(6) The Poteau group of Indian territory (Drake) corresponds about to that part of the Missourian below the Plattsmouth limestone, and entirely overlies the Poteau of Arkansas.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 197-216 APRIL 30, 1901

WISCONSIN SHORE OF LAKE SUPERIOR

BY GEORGE LUCIUS COLLIE

(Presented before the Society December 29, 1900)

CONTENTS

Introduction

This paper is the result of a series of observations taken during the summer of 1900. The descriptions cover that portion of the shore between point Detour, the northernmost point of the Wisconsin mainland, and the Montreal river, the boundary between Wisconsin and Michigan.

Point Detour is at the extremity of an unnamed peninsula which juts out into the lake; it is here called Chippewa point. This peninsula

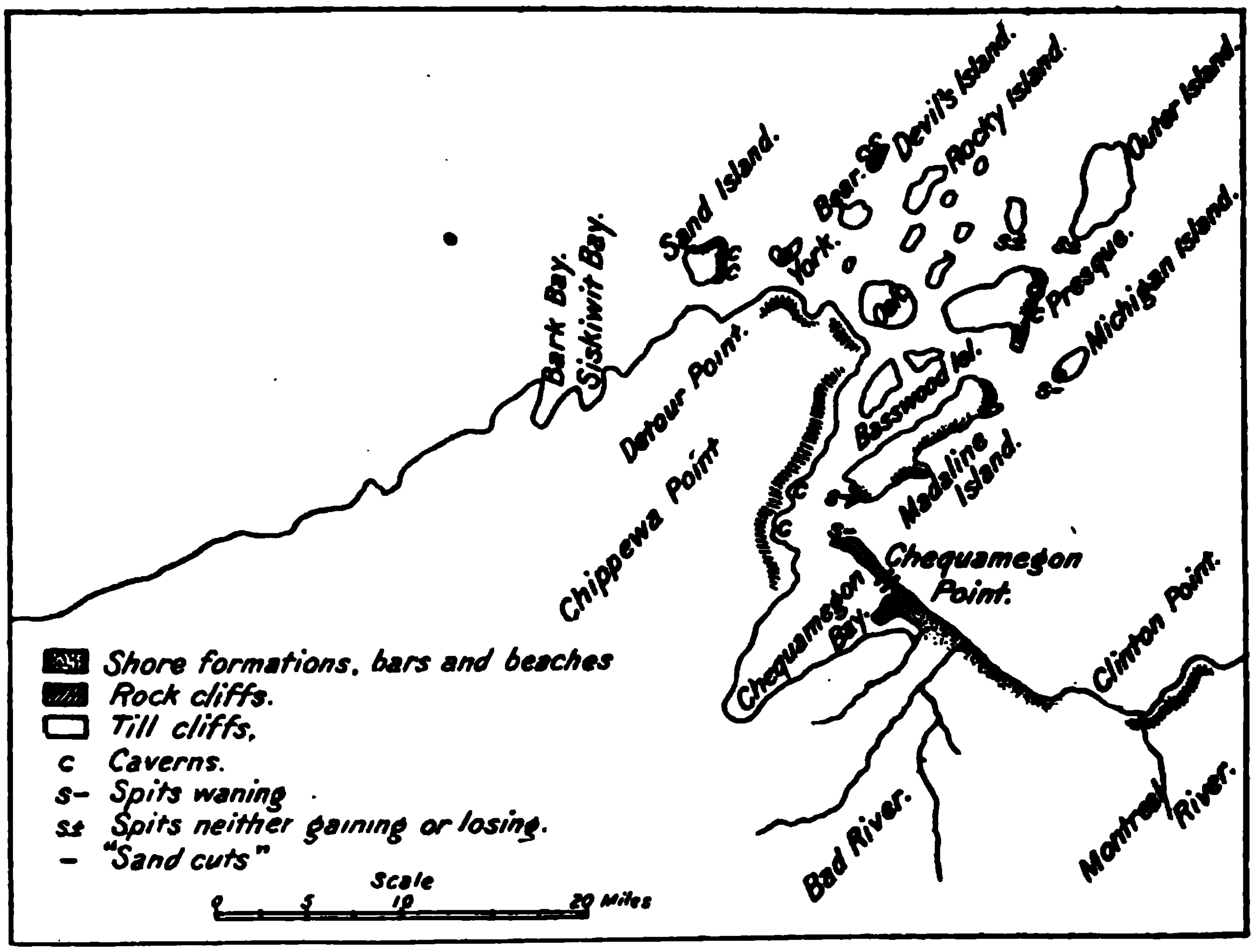


FIGURE 1.—*Chippewa Point and the Apostle Group of Islands.*

forms the western shore of the indentation known as Chequamegon bay. Lying about the peninsula and stretching across the mouth of the bay is a cluster of islands, the Apostle group. This paper deals with the shore phenomena occurring in this bay and on the Apostle islands. It is not planned to enter into a discussion of the older shore phenomena, but simply to consider those which have arisen since the lake reached its present level.

General Geology of the Region

RELATIONS OF ROCKS AND GLACIAL MATERIAL

At the Wisconsin-Michigan line the rocks, Keweenawan in age, are mainly sandstone and shales, dipping to the northwest at high angles,

sometimes even reaching a vertical position. The Keweenawan rocks continue to outcrop at rare intervals along the lake shore for a distance of four miles. At Clinton point the Cambrian sandstone takes their place and continues to be the only rock formation exposed on the lake shore until Minnesota is reached. The sandstone, locally termed the Lake Superior sandstone, is of such importance that it will receive separate treatment, and need not be further considered at this point.

Generally the consolidated sediments are masked by glacial material, either till or washed deposits of silt and gravel. The clay predominates in all the cliffs, although washed deposits replace it in a few instances. This is especially true of the shores at the foot of Chequamegon bay. The thickness of the glacial debris is great and effectually hides the underlying formations in most localities, except where wave action has removed the glacial deposits. A well-boring at Ashland shows that the glacial drift at that point is about 300 feet thick.

LAKE SUPERIOR SANDSTONE

Equivalency and general character.—The Lake Superior sandstone has been derived from the Penokee and Douglas ranges, whose ridges still rise conspicuously above the general level of the region. The sandstone, which is probably the equivalent of the Potsdam, is a highly ferruginous, thick-bedded rock. The iron present does not act as a cement; it simply coats the grains of silica, which chiefly compose the formation. The cement is silicious and is usually present in such quantities as to render the rock very resistant to weathering. Fine clay frequently forms the matrix of the sandstone, and in such cases the sandstone is friable and weathers readily. The clay often becomes so abundant that the rock takes on shaly characteristics and becomes laminated. This is true of the exposures at the north end of Sand island. In addition to its dissemination throughout the sandstone, the clay often occurs in lenticular masses, varying in size from a fraction of an inch to a diameter of several feet. Apparently they are not nodular in character, but are masses of clay which accumulated as the sand was deposited. Weathering readily removes these accumulations, giving the rock a characteristically pitted appearance.

Cross-bedding.—Cross-bedding is a common feature of the sandstone; it occurs in all of the layers exposed to examination. Its most characteristic habit is the large scale on which the flow and plunge structure is developed. This becomes especially noticeable along the shore of the lake, where the waves have removed the soil and left a large area of rock surface exposed. In such localities the structure reminds one of the arrangement of blocks in an ice jam.

Ripple-marks.—Ripple-marks are another common feature of the sandstone. Three types are recognizable, each of which is abundant. The first type is one in which the two slopes of the ripple-marks are unequal, both in length and pitch, and the crest is sharp normally. This type occurs in those layers which contain a large percentage of clay, and are for that reason more impressionable. In the second type the two slopes are nearly equal and the crest is rounded. The third type is one in which two sets of ripple-marks intersect at varying angles, two sets of ridges being thus formed, between which lie rudely quadrilateral depressions.

Mud-cracks.—Associated with the ripple-marks, often on the same slab, are abundant mud-cracks. Frequently iron has segregated in the original cracks, and on exposed surfaces the more resistant iron stands out in welt-like ridges.

Pebbly sandstone.—Thin bands of pebbles occur in the sandstone, occupying small areas. The pebbles are usually well water-worn and carefully assorted. These features of the sandstone, together with those above mentioned, indicate the shallow-water conditions under which the sandstone was laid down.

Thickness.—A well-boring at Ashland shows that the sandstone at that point is over 2,500 feet thick. The sandstone thins out toward the contact with the Keweenawan southward. It is reasonable to suppose that it also thins out to the north as the distance from the original source of supply increases. It is probable that the thickness at Ashland represents, approximately, a maximum.

General Topography of the Region

The most prominent topographic feature of the area under consideration is the Penokee and Douglas ranges, the former of which rises to a height of 1,000 feet above the level of the lake. At the Montreal river the foot of the range forms the lake shore, a low cliff, whose face is the dip plane of the rocks. Immediately across the river the range trends to the southwest, gradually diverging from the westward trend of the shore. The highest portions of the Penokee range in Wisconsin are 15 miles from the lake.

The north face of the range, at the contact with the sandstone, is a steep escarpment of varying height. This northward-facing cliff is without question a fault scarp.* This is shown by the extreme brecciation of the rocks at the contact; also by the upturned condition of the sandstone, which is on the down-throw side. No exact figures can be given as to the amount of the displacement, but it probably amounts to several hundred feet. The width of the zone of brecciation and the upward

*Grant: Copper-bearing Rocks of Douglas Co., Bull. Wis. Geol. Sur. No. 6, pp. 17, 18.

bending of the sandstone back to some distance from the fault plane indicate considerable movement. It is not to be asserted that the contact between the Keweenawan and the Potsdam is everywhere expressed in a fault, but this is a common relationship. The contact is everywhere one of unconformity, whether faulting has taken place or not.

The ranges extend across the state to the Saint Croix river, but in ever diminishing prominence as topographic features. The rocks composing the range dip sharply to the northwest and form the southeastern boundary of the great syncline in which the western portion of lake Superior lies. South of Ashland the range divides, one portion extending up into Chippewa point, forming the backbone of that peninsula. The other portion, as already indicated, trends across the state and extends into Minnesota. To these ancient ranges is due much of the ruggedness of the region. No very characteristic topography occurs within the ranges. Frequently sharp ridges are found, though a low, broad ridge is more common. The original topography is greatly altered by glacial deposits, and on that account it is difficult to definitely characterize the topography. The mountain summits form a very even skyline as a whole.

Between the ranges and the lake there lies a narrow plain, averaging 8 miles in width. The underlying rock is the Lake Superior sandstone, already described. It rarely appears at the surface in outcrops, as it is effectually hidden by glacial debris. The sandstone rises high on the flanks of the ranges, in some cases 200 feet above the level of the lake. From this height it slopes gradually toward the lake, where it appears in cliffs which never exceed a height of 60 feet. The surface deposits consist of an underlying till covered by washed deposits of silt. All of the glacial deposits have an intense red and reddish brown color, due to the large iron content, a characteristic which is prominent in all of the Lake Superior deposits.

Most of the streams of the region rise on the northern slopes of the ranges, though a few of the master streams, like the Montreal and the Bad, break through the ridges in narrow gorges, locally termed "gaps." Where the streams pass from the older rocks to the sandstone, falls and rapids usually occur. These streams traverse the sandstone belt in narrow meandering canyons, which indicate the comparative youthfulness of the rivers. The opportunity for the erosion of these gorges has come about through the slow withdrawal of the lake, though earth movements may have been a factor as well. The position of the lake level is the position of local baselevel, and as the lake has been lowered, the local baselevel has been reduced correspondingly. New opportunities for stream erosion have been given with this constant lowering of the lake level from the Duluth stage to the present time. This could take place

without the intervention of earth movements as a necessary accompaniment. The depth of the stream gorges rarely exceeds 100 feet, and the energy of the streams is expended chiefly in deepening the channel rather than in any attempt to widen it. The rivers are not graded, and there is a constant succession of falls and rapids. The most important fall in the region is that of the Montreal river within half a mile of the Superior shore. There is a plunge of 100 feet in a series of cascades, the last one of which is 40 feet high. The fall is probably an inherited one, coming from the Keweenaw-Potsdam contact, which lies at some distance out in the lake at present.

There is no objection to the supposition that the sandstone once covered the foothills of the Penokee range, and that the fall began at the contact of the two formations as a result of its passage from the harder rocks of the Keweenawan to the weaker layers of the Potsdam.

On the whole the topography of the sandstone belt is not marked by any conspicuous features; the plain is smooth and without marked prominences. Stream erosion is responsible for the only notable topographic characters.

The topography of the Apostle islands is similar to that of the sandstone belt on the mainland. The inner islands are more rugged than the outer ones, the latter being flat, table-like areas of rock without much glacial debris resting on them. On the whole, the former are covered with a much heavier mantle of drift than are the latter. The trend of the islands and of the channels separating them corresponds to the general trend of the pre-Glacial valleys and of the shoreline on the mainland. This indicates that the islands have resulted from the drowning of pre-Glacial valleys and the consequent isolation of the higher portions of the land surface. Well developed valleys, probably of pre-Glacial origin, are found on the mainland at the present time, which are connected with each other by sags over the intervening divides. A slight depression of the land would cause the flooding of these valleys by the waters of the lake and the formation of several new islands. Should the lake level rise 30 feet, the promontory which lies between Buffalo bay and Frog bay would be cut off from the mainland and an island would result. If the lake level should rise 50 feet, Detour point would be cut off and an island formed, and the same is true of Bark point and Siskiwit point. In such cases it is natural that the trend of the islands should agree with that of the mainland.

On the contrary, should the lake level be lowered, not only would the islands be increased in size, but a number of them would disappear as islands and would again become mainland ridges and promontories. A lowering of the lake to the amount of 10 feet would cause Sand island

to be joined to the mainland. A reduction in level of 50 feet would result in the obliteration of the following islands: Raspberry, York, Oak, and Basswood. If the lake should be lowered 60 feet, Bear island would be joined to Raspberry, Otter to Oak, South Twin to Rocky, Michigan to Madeline, and Madeline to the mainland. The islands are simply a phase in the history of the lake, their existence or their obliteration depending on relatively slight fluctuations of the lake level.

A brief statement regarding the topography of the lake bottom should be given, in addition to what has been said regarding the land surface. Along the Michigan and Minnesota shores there is a sudden descent from the shoreline to the one-hundred-fathom line. This is due to the fact that the Keweenawan rocks, which form the shores, dip at high angles and plunge rapidly to considerable depths. The reverse is true on the Wisconsin shore. Here the rocks are not the steeply dipping members of the Keweenawan synclinal, but are composed of Potsdam sandstones in horizontal beds. These Potsdam sediments have filled the western end of the syncline in large part and deeply buried the Keweenawan. On this account there is a marked contrast between the Michigan and Wisconsin shores, both in respect to trend and in respect to topography. The twenty-fathom line approaches the Minnesota shore within a mile or two. In Wisconsin, on the contrary, it passes outside the Apostle group at a distance of 20 miles from the mainland. On approaching Michigan it returns in close proximity to the shore again. The fifty-fathom line parallels the twenty-fathom line approximately. It passes far out around the Apostle islands, at a distance of 30 miles from the mainland. As it approaches the Minnesota shore, however, it returns close to the shore once more. The arrangement of these contours indicates that a plateau of rock extends to some distance into the lake, and, in addition, it shows that the plateau is an extension of Chippewa point. The extent of this platform gives an intimation of the widespread distribution of the Potsdam sediments. It also indicates the degree to which the ancient Lake Superior synclinal was filled at its western end.

Recent Changes in Lake Level

Before discussing the shore formations it will be necessary to consider certain of the recent changes in the level of the lake, because these changes have a bearing on the deposition of the shore formations and on their extent. As is well known, the Pleistocene stages of the lake were higher than the present stage by several hundred feet. The lowering of level has been one of the marked features of the lake history, and this has not been accomplished without oscillations, for there have

been times when the waters advanced on the land instead of receding from it; but these were temporary stages. The total result, however, has been a gradual recession of the lake level to its present position. The last well defined stage, before the present one, may be called the Madeline stage, from the fact that the benches made by it are well defined on Madeline island. At that time the lake stood at least 10 feet higher than at present. The terrace made during this stage is characterized by its distinctness. A few sea-cliffs, also of this period, are found at some distance from the present shore of the lake, and they, too, retain their original features in a marked degree. In all probability the terrace and cliff are of recent origin.

Closely associated with the sea-cliff and the bench at its foot there are spit formations, in two instances at least. The spits were formed evidently during the retreat of the lake from the Madeline stage to a lower stage. As the lake level was lowered the spits were built out, until the Grant Point spit at the south end of Madeline island exceeded a length of one mile. This length was obtained during the time of maximum withdrawal of the lake.

Succeeding this maximum withdrawal there has now appeared a re-advance of the lake on the land. This apparent rise of the lake is shown by two proofs: (*a*) The destruction of shore deposits, especially spits and bars, and (*b*) the drowning of the lower courses of streams which empty into the lake. Under the first head may be mentioned the destruction of spits such as that on the south end of Madeline island, or of bars such as the Chequamegon Point bar. The former may be taken as a type of the waning shore deposits. According to well authenticated tradition, this spit once extended for a distance of 5,000 feet from the south shore of the island. Nothing is now left but a shoal to mark its former extent. This shoal shows that the extent of the spit has not been exaggerated. It extends into the ship channel for a distance of at least one mile. The shoal is a destructional form, not a constructional one; it could not be formed under present conditions as a constructional shoal; it is simply the foundation—a remaining remnant—of the Grant Point spit. It is the testimony of a number of old residents on Madeline island that the spit extended out into the channel at least 2,000 feet within 50 years. The destruction of the spit has been a comparatively rapid one, therefore. What is here stated with regard to this particular formation is also true of others, but exact statements are wanting. The only reasonable explanation of this rapid destruction of spits is that already indicated, namely, the advance of the lake on the shore, due apparently to rise of lake level. In this connection it may be of value to refer to Gilbert's * "Recent earth movements in the Great Lakes re-

gion." This article advances evidence which indicates a southwest tilting of the region described. In the case of lake Superior this tilting movement would flood the head of the lake, causing an apparent rise of the lake level. One of the results of this rise would be the destruction of shore deposits made while the lake stood at lower levels. The destruction of the spits already noted tends to confirm the truth of Gilbert's contention that the lake is invading the land because of a southwest tilting of the lake region. The direction of tilting is assumed by Gilbert to be south 27 degrees west—that is, the movement is more to the south than to the west. This is undoubtedly true, and it may be questioned whether the movement is not even more to the south than he has assumed. It is within bounds to say that the maximum rate of bar destruction takes place about Chequamegon bay; but if the tilting were well to the west this would not be true, since under such circumstances the maximum attack would be on the bars at the head of the lake. On the other hand, if the tilting is more southerly the tendency would be to cause a maximum destruction anywhere on the south shore, where wave action is most violent. Under the present conditions of exposure, other things being equal, the bars and spits about Chequamegon bay will suffer greater destruction than the bars at the head of the lake. This is in part due to the fact that wave action has its effectiveness reduced by reason of the gradual contraction of the banks of the lake in the neighborhood of Duluth and Superior.

The second proof of apparent rise of the lake is the flooding of the lower courses of streams. Some of the larger streams have true estuaries. This is especially true of Saint Louis river at the head of the lake. In a lesser degree the Bois Brulé, the Kaukaugon, and the Bad rivers possess the same features. They are all broad and deep streams, when the limited extent of their drainage areas is considered. As these streams approach the lake, the current becomes more sluggish and they take a meandering course to their outlet. The swamps through which they pass in the lower part of their course are flooded in the vicinity of the stream, though relatively dry and firm away from it. This is due to the backing up of the lake waters into the river and the consequent flooding of the region in the neighborhood of the river. All of the streams on the south shore of the lake in Wisconsin show drowned features, though there are differences in the degree of the drowning. If the tilting of the land is to the southwest, an increasing amount of drowning should be expected as the head of the lake is approached. The writer is unable to find satisfactory evidence of such progressive increase of drowning. It is true that Saint Louis river exhibits the estuarine features on a larger

* Eighteenth Ann. Rept. U. S. Geol. Survey.

scale than other streams, but this is what might be expected on the supposition that the southwest tilting of the land has crowded the waters of the lake toward its head. The Saint Louis is the master stream of the region. Before the tilting took place, it had eroded a much wider and deeper valley than other streams had been able to do. As a result the Saint Louis would naturally show the drowned features in a greater degree than any other stream in the region. If a series of streams possessing approximately the same size be taken between Point Detour and West Superior, progressive drowning might be shown if the conditions affecting these streams are the same. The writer has been unable to find any evidence of an increase in the amount of drowning of such streams toward the head of the lake. However, this proves little, for local conditions may mask or wholly obliterate evidence of this kind. The quite uniform conditions of drowning of streams along the Wisconsin shore tends to confirm the statement already made that the direction of tilting is southerly rather than westerly. Under such conditions the drowning of the streams would be approximately the same all along the Wisconsin shore of the lake.

Shore Formations

CHEQUAMEGON BAY AND ITS HISTORY

The present bay has existed only during post-Pleistocene time, but a much larger bay existed here after the folding of the Keweenawan rocks. This ancient bay occupied one of the two minor synclines into which the Lake Superior synclinal was divided as a result of the folding. At the opening of the Potsdam the bay had an area of at least 375 square miles. This area was greatly reduced by the accumulation of Potsdam sediments within the Chequamegon syncline. Judging from the fact that Potsdam sandstone is found high on the flanks of the syncline, it is probable that the syncline was largely, if not wholly, filled by Potsdam sediments. During the interval between the close of the Potsdam and the opening of the Pleistocene the sandstone was removed from the syncline, in part, by the various agencies of erosion, and a new basin thus resulted. During the Pleistocene the basin was modified by ice-action to an unknown degree. When the present regime opened, a basin of considerable size existed, ready to be occupied by the postglacial waters. During the Madeline stage, the area of the bay was about 75 square miles. Its present area is nearly 45 square miles. This area is being reduced continually by the encroachment of marsh deposits. The water of the bay is shallow, nowhere exceeding 30 feet in depth, with an average depth of less than 20 feet. A bar which has been thrown across the mouth of the bay has facilitated the accumulation of sediments.

There are 30 square miles of marsh deposit behind this bar at present, and these deposits are being extended at a rapid rate.

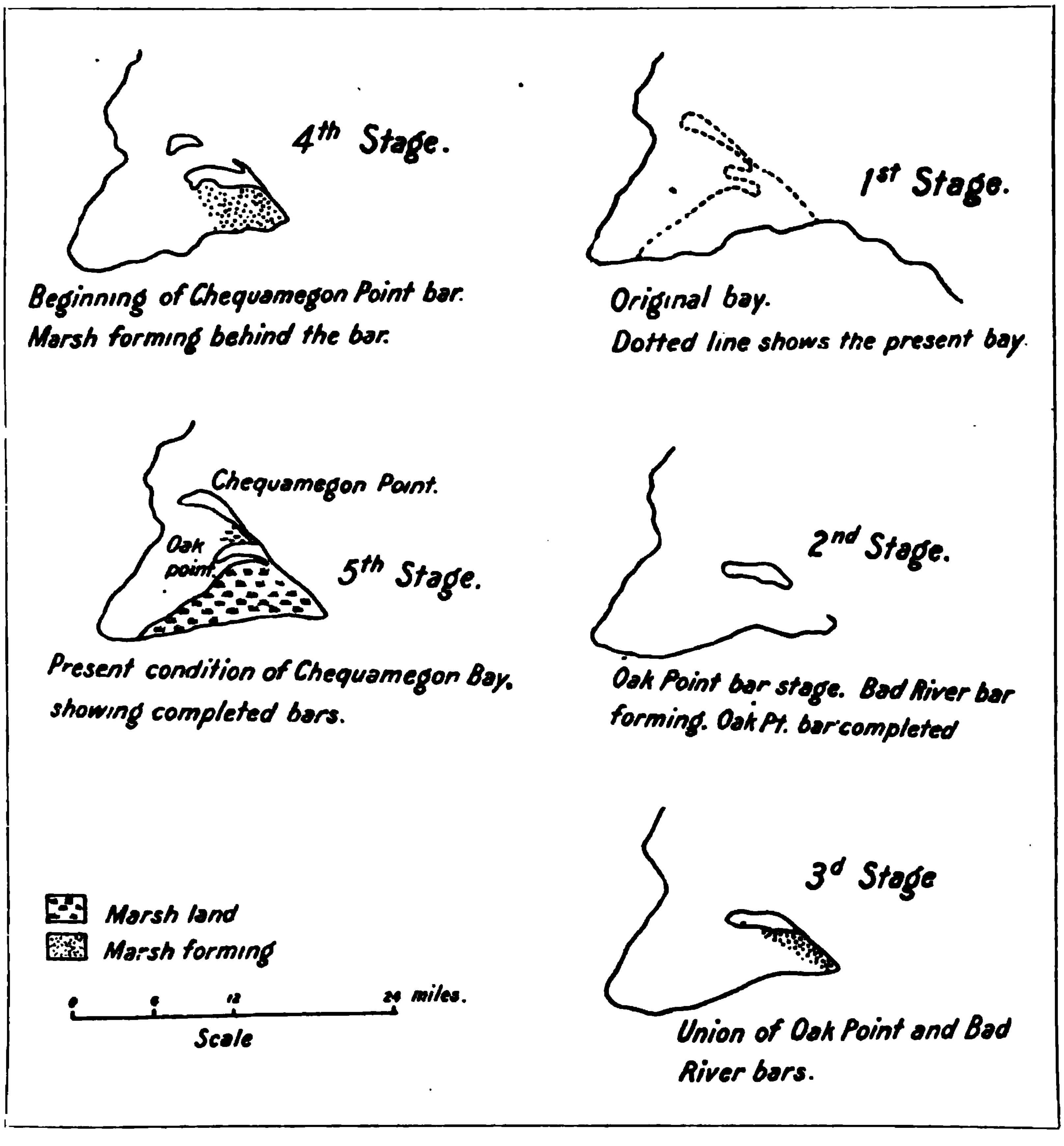


FIGURE 2.—*History of Chequamegon Bay.*

The different stages in the history of the present bay are illustrated in figure 2. An outline of the changes which have taken place will now be given.

OAK POINT BAR

The first step in the modification of the bay was the formation of a bar now known as Oak point. This bar was formed parallel to the then existing east shore of the bay, at a distance of several miles from the shore. The original bar was about 5 miles long. It is still well preserved, and its features can be studied readily. It is a broad bar, aver-

aging 100 rods in width, and is made up of several parallel ridges, the oldest of which lie inside the bar toward the mainland.

Behind the bar is an extensive marsh, which reaches across to the former shoreline of the bay. In general the marsh is well developed. Tamaracks grow in many portions of it. It has reached a higher degree of development than any other marsh of the region, and for this reason it is assumed that it is the oldest marsh in Chequamegon bay.

The formation of a marsh in an exposed body of water, such as Chequamegon bay, presupposes the existence of a barrier, behind which the marsh deposit may accumulate. The older the marsh, the older the barrier, other things being equal. Because the Oak Point marsh is the oldest of that type of formation, it is assumed that Oak Point bar, which lies in front of it, is the oldest of the bar formations in Chequamegon bay. It may be questioned whether the relative age of a bar can be determined by means of the character of the deposits behind it. In the case of the Chequamegon Bay deposits it is believed that the method is applicable, under the conditions which exist in that region.

BAD RIVER BAR

The second step in the modification of the bay was the formation of a bar which connected the mainland with Oak Point bar. This bar is called Bad River bar, because Bad river breaks through it in its passage to the lake. The bar extends from the point where the old shoreline of Chequamegon bay turned abruptly from its northwest trend to the southwest, a point about 3 miles east of Bad river.

Evidently the bar began as a spit, which formed because of the abrupt change in the trend of the coast line. The spit gradually became extended until it joined Oak Point bar. The two combined formed a hook nearly 9 miles long. Bad River bar is very narrow, averaging but a few rods in width. It consists of a single ridge, whose upper portion is composed of wind-blown sands. Apparently no deposition is going on in connection with the bar, and a well defined nip is seen all along the lake side of the bar. Marsh deposits completely fill the lagoon behind the bar. The Bad river traverses the marsh, being deflected to the west as it approaches the bar. The mouth of the river is migrating westward continually. This fact is shown by the pronounced nip on the west bank of the stream, and also by the fact that a spit is forming on the east bank, pushing its way across the river and deflecting it more and more to the westward.

CHEQUAMEGON POINT BAR

The third step in the history of the bay was the formation of the long hook-shaped bar locally called Long island. This bar consists of two

portions, which were formed probably at different times. One portion, the west end, is a broad bar made up of several parallel ridges. The other portion, the east end, is a single narrow ridge, which joins the expanded western portion to Oak Point bar.

The broad portion of Chequamegon Point bar lies parallel to Oak Point bar. It is the oldest part of the bar, and was tied to the other bars by a spit, which formed at the abrupt bend made by the junction of Oak Point and Bad River bars. Naturally at this point a spit would develop, and the development continued until the spit joined the Chequamegon Point bar. The total length of the completed bar is about 10 miles. This bar is so recent in origin that no noteworthy deposits have been formed behind it; those which do occur are found chiefly in the narrow lagoon between Oak Point bar and Chequamegon Point bar. The completed Chequamegon Point bar is a hook similar to Oak Point bar. For more than half of its length the bar is very narrow, consisting of a single ridge, whose structure is due in part to wind action. Shifting sands move across the narrow strip from the lake to the bay and form dunes of small extent. In its wider portion, the bar is made up of several parallel ridges, between whose depressions the lagoons and marshes occur. The largest of the lagoons lies on the bay side of the bar, and extends 4 miles parallel to the bay shore. The ridges have been formed one after the other, the oldest being situated on the bay side. The older ridges are covered with thickets of "jack" pine, but the younger ridges are destitute of vegetation or carry small quantities of lichens, such as Cladonia, or scattered clumps of the "sand-cherry." Pronounced nip occurs on the lake side of the bar for much of its length, indicating the general destruction of the bar.

Toward the west end of the hook deposition is going on, but it occurs only within narrow limits. The deposition takes the form of a shoal which lies out in the lake a few rods, evidently the precursor of a new ridge. The bar as a whole was quite intact until the year 1891. Inlets had been made through it before that time, but these speedily closed up under continued wave action. In the year mentioned the bar was breached at two points during a series of severe northeast storms. The passages thus made have remained open to the present time and are continually growing wider. These passages are locally termed "sand-cuts," and that appellation will be used in this paper.

In all probability the wind does the preliminary work in preparation for the sand-cuts. They are formed only on the narrow portions of the bar, where there is comparatively little material to be removed. The first step in the formation of a sand-cut is the development of a depression across the ridge of sand composing the bar. This depression is

produced by the wind, which gouges out funnel-shaped depressions in the loose sand. The wind-gouged funnel is finally developed into a depression which extends across the bar. Several funnels now exist on the bar near the sand-cuts. They are cone-shaped, with a depth of from 6 to 8 feet and a diameter at the top of from 12 to 15 feet. The wind tends to remove the sand from either side of the depression, and a gap results which may extend across the bar. During severe storms the waves reach these gaps, and they speedily erode a channel through them. It is believed that the preliminary work of the wind is a very essential factor in the formation of the sand-cuts. During storms the waves run high on the face of the bar. Their destructive work is offset in large measure by their constructive work in such localities. On this account the waves are not able, as a rule, to breach the bar of their own accord. If, however, a depression already exists, such as those made by the wind, the water is poured through it during storms, and a passage is soon eroded in the uncompacted sands. In such cases as these a relatively feeble current of water accomplishes more because of its eroding and transporting power than the heavy blow of the waves delivered on the sand, which may tend to construct rather than to destroy.

Two sand-cuts are now formed across Chequamegon Point bar; one of these is about 2,500 feet wide, the other somewhat narrower. These cuts have maintained themselves for 10 years, and they are constantly growing wider, in spite of attempts on the part of the government to close them up. Behind the cuts, on the bay side, a new bar is being formed parallel to the old one. This indicates a tendency for a new bar to form as the old one is destroyed, though in a less exposed locality. The littoral currents, which used to flow westward along the bar, are now diverted and flow through the sand-cuts. This diversion of the currents has had some effect on the rate of erosion both in the sand-cuts themselves and also along the bar. The diverted currents formerly flowed by the end of Madeline island after leaving the Chequamegon Point bar. Fishermen state that the erosion in these localities is less than it was before the diversion of the currents, but no accurate statement can be given as to the exact difference in the amount of erosion.

LAGOON AND MARSH DEPOSITS

Immediately behind the Chequamegon Point bar there are no marsh deposits, except in the narrow lagoon between Chequamegon and Oak Point bars. A swamp has formed here for a mile or so from the point of junction of the two bars. The stages of marsh formation are well illustrated in this lagoon. A shoal is the first condition. On this shoal eel grass obtains a foothold. The second stage is reached when the eel

grass, which readily holds debris carried in the water, has built up a shoal within a few feet of the surface. On this new shoal aquatic vegetation such as reeds, rushes, sedges, and wild rice take root, and these bring about true marsh formations. The last stage is the meadow condition, determined by the accumulation of debris sufficient to allow the land vegetation to gain a foothold. The east side of Chequamegon bay is entering upon the preliminary stage of swamp formation. The average depth of the water is only 10 feet, a depth which permits the growth of eel grass. Already this type of vegetation has gained a widespread distribution in these shallow waters.

ISLAND SPITS

The formation of spits is chiefly confined to the islands of the Apostle group. Spits form invariably on the south end of islands in this region. This distribution is due to the direction of the prevailing winds and currents, which set in from the northeast or the northwest, as a rule. Spits are not found on all of the islands. A combination of factors is necessary to allow their formation. Among these factors may be mentioned the following: Size of the island. Many of the islands are too small to furnish sufficient debris for spit formation. Another factor is the presence of formations that can be attacked readily by erosive agents. At the same time the debris must be of such a character that it can be transported with some degree of ease by the waves and currents. For example, on those islands in which glacial debris is abundant, other things being equal, spits will occur. On the other hand, if the waves must attack the consolidated sediments for material, the spits are either absent or insignificant in size. Usually the cliff debris found along the shores of the islands is in the form of coarse blocks, much too large to be transported. Ultimately these blocks will be reduced by the waves to transportable sizes. As yet this kind of work has not gone on to any great degree, for Potsdam sandstone debris is not very common in the spit deposits.

Another factor that has helped to determine location of spits is the slope of the lake bottom. Frequently the slope is so great that a long period of time must elapse before enough sediment is collected to reach the surface of the water, even though other conditions be favorable. Another condition that controls the formation of spits is the position of the islands with reference to each other, and also with reference to the prevailing currents. Islands which lie in the lee of others, and are thus protected, in a measure, from the waves and currents, are free from these deposits, as a rule. The most exposed islands, like Outer, Michigan, and Cat islands, possess spits, while other less exposed islands are with-

out them, though other conditions may favor their presence. The existing spits on the islands are small, usually extending but a few rods into the lake. Formerly much more extensive spits occurred on the islands, but they have disappeared gradually, until at the present time no extensive deposits of this type are found, though shoal deposits extend out into the lake from the end of certain spits, and these shoals indicate in some degree the former extent of the spits.

TOMBOLOS

This type of shore deposit is found in a few instances. The best example is found on Presque isle. In this particular case two islands, once separated by a channel of water at least 2,000 feet wide, are connected by a broad bar of sand and gravel. York island is another example of the same phenomenon. Here two small rocky islands are connected by a bar of sand a hundred yards long. Sand island is tied to the mainland by a bar of sand at least two miles long, which has not as yet appeared above the water. The depth of the water over the bar is slight, not exceeding seven feet—a good example of an incipient tombolo.

BEACHES

The various types.—Beach deposits are common both on the mainland and on the islands. There are four recognizable types, namely, the platform, the barrier, the cliff, and the storm beach.

Platform beach.—This type is found on Michigan and Madeline islands. Its chief characteristics are a looped bar or ridge of gravel and sand formed on an old wave-cut platform, the whole ridge inclosing a lagoon within. The Michigan Island occurrence is a good example of the type. During the Madeline stage the lake cut a well defined bench and sea-cliff. The cliff itself is cut in glacial debris and reaches a height of 40 feet. It extends across the island and is extremely well defined. In front of the cliff stands the bench, covering possibly 300 acres. It is triangular in form, with the base resting against the base of the cliff. The bench stands several feet above the lake, as a whole, but there is a gradual slope from the cliff to the lake. Where the sloping bench meets the lake the waves have thrown up a ridge of sand and gravel about the periphery of the bench. Naturally this forms a looped bar, because of the shape of the bench. This ridge is broad and low, sloping in front toward the lake like an ordinary beach. Indeed, it has the characteristics of the usual beach formation. Within the looped bar is a lagoon, which covers several acres, though it has become filled in large part with debris.

Barrier beach.—Barrier beaches occur chiefly on Madeline island, the largest member of the Apostle group. They have been thrown across the bays between the more prominent promontories. They only occur where the neighboring cliffs are composed of glacial drift, and thus furnish an abundance of transportable material. The normal type is a broad low bar, chiefly of sand, cutting off lagoons which have become more or less filled. The best example is the barrier beach connecting the "Old Mission" with the town of La Pointe. These beaches have helped greatly in smoothing the originally irregular shores of Madeline island.

Cliff beach.—This type of beach is formed at the base of the long line of clay cliffs between the Bad river and the Montreal. A narrow bench is cut out at the base of the cliff, and here the coarse debris is deposited in a characteristic way. The shoreline in this region is quite straight. There are few pockets in which debris can be gathered. Much of the material derived from the cliffs is too coarse for ready transportation. Under these conditions the coarse shingle and boulders are thrown up against the face of the cliff. The base of the deposit rests on the narrow bench at the foot of the cliff. The beach thus formed presents a steep front, exceeding 30 degrees, as a rule. The coarse materials composing it are piled high against the cliff face, frequently from 12 to 15 feet. The coarse debris is packed firm by the repeated blows of the waves. The beach is usually so massive that it is thrown across the courses of streams without being disturbed by their presence, the water of the streams only entering the lake by seepage through the coarse gravels. Occasionally pockets occur in the shoreline of the cliffs, and in such cases the character of the beach changes. Finer materials obtain a foothold under such circumstances, and the beach is not built up as high, nor are its slopes as steep.

Storm beach.—The storm beach is found chiefly on the exposed bars, where the sand is shifted to and fro by each storm. Temporary ridges of sand accumulate, which are several rods in length. Usually the storm beach is attached at one end to the parent beach, the other end being free. These beaches are constantly forming and disappearing, according to the violence of the storm and the varying direction of the wind.

SHOALS

The streams which enter the lake form delta deposits, which are greatly modified by wave and current action. Deltas of regular form are not built up in the face of the lake storms. The deposits should be designated as shoals rather than deltas. The debris is scattered about widely by waves and currents. It is only here and there that sufficient mate-

rial accumulates to form true shoals. The most extensive shoal deposit in the region is that off from the mouth of Bad river. The shoal extends out into the lake for a distance of 5 miles, its position being marked by the changed color of the water above it and by the discoloration of the water during storms. On the average, the water on this shoal is shallower by 20 feet than the surrounding waters.

The major portion of the shoal lies to the west of the river mouth, carried to that position by the prevailing direction of the currents.

Though the watershed of lake Superior covers a relatively small area, yet its slopes are so steep and there is so much loose debris on the surface that the conditions for the transportation of sediment into the lake are very favorable. The debris thus brought in is carried long distances by the strong currents of the lake. The writer has seen the lake discolored at Devils island by sediments brought in by the Nemadji and Saint Louis rivers 90 miles away. This wide carriage of debris tends to form shoals over vast areas. Especially is this true in a limited and narrow area such as that represented by the head of lake Superior.

Wave Erosion and its Topography

Caverns

Caverns occur on those portions of the islands and mainland which are well exposed to wave action. The best examples of this feature are found on Devils island. The caverns are formed in those layers of rock exposed to maximum wave-action. As the vertical range of the waves is not great, the caverns rarely exceed a height of 15 feet above the level of the water. In many cases they are gouged out to quite a depth below the surface. The caverns extend back to a maximum distance of 100 feet. Usually their depth is much less than this. In a number of instances the caverns are practically continuous, their broad, low portals being separated only by a thin wall of rock, or possibly a few intervening pillars. The amount of clay in the sandstone is the chief factor in determining the form and size of the cavern. The more silicious portions of the rock are cavernless as a rule. On the distribution of the clay depends, in large part, the nature of the architecture, the presence of pillars, the form of the portal, the detailed fretwork, all of which add so much to the charm of these occurrences.

The erosion of these caverns is slow, as the water carries little sediment with which to do effective work. The retreat of the coast, however, is accomplished chiefly through the falling in of the cavern roofs. The process is an exceedingly slow one. The waves plunge into the caverns with terrific force, but they do little except to wash out the soft

clay or break the supporting pillars by their mere momentum. On Devils island the caverns number two score or more, and a continuous series of them are presented for a distance of a mile. Their chief interest lies in their fantastic architecture. Caverns also occur on Presque isle, Sand island, and others of the Apostle group. They are also found on the mainland, especially along the shores of Chippewa point.

COVES

On exposed sandstone cliffs, coves are formed by erosion along joint planes. Master joints with a northeast-southwest trend are common in the sandstone. These joints stand head on to the most violent storms, those which come from the northeast. The waves gradually open these joint planes until a cove is finally made. A typical cove is a narrow canyon-like chasm, not exceeding 10 feet in width. Its height, which depends on that of the cliff, may be 30 or 40 feet. The cove extends back, following the course of the joint for a distance of several hundred feet, its walls gradually contracting as they are removed from the action of waves. The floor of the cove slopes upward gradually until it reaches the top of the cliff. Such a floor is an inclined plane, up which the water is forced with great violence, bearing with it coarse shingle and boulders, which are finally deposited on top of the cliff. It is common to find a mass of boulders at the shore end of these coves. The best example of this feature is Stella cove, on the east shore of Presque isle.

CLIFFS

The loftiest cliffs of the region are those composed of glacial drift, chiefly boulder-clay. An impressive example of this type is seen on the north end of Oak island, where the cliff reaches the height of nearly 200 feet. The rate of wear on exposed clay cliffs is rapid, in spite of the cliff beaches at their base. None of these cliffs approach the perpendicular, but they maintain a high angle of slope, frequently exceeding 40 degrees. The sandstone cliffs are less common; they reach a maximum height of 60 feet. As a rule, these cliffs are perpendicular, their recession being due to undermining of the base by wave action. Less than one-fifth of the shoreline is bordered by sandstone.

BENCHES

At the base of cliffs, benches are found. Those at the foot of sandstone cliffs are narrow, rarely exceeding a width of 10 rods, and averaging much less than this. From the foot of the clay cliffs a bench extends for a distance, in some cases, of several hundred rods, as is well exhibited on the east shore of Madeline island. These benches become

the seat of shoals and incipient bars, the latter forming at a distance from the shore, but parallel to it.

STACKS

Isolated portions of rock are often cut off from the parent cliff, especially on the exposed Apostle islands. The separation occurs chiefly through wave action opening and enlarging joint planes. The stack may be separated but slightly from the parent mass, as is the case with Lone island, or a wide channel may intervene, as in the instance of the Little Manitou, which now stands 100 rods from its former connection. All types of stacks occur, from the massive to the slender skerry or drong. In some cases these pinnacle forms may be overturned and only projecting points remain, such as are seen about the Sphinx.

SUMMARY

The region described in this paper is that portion of the Wisconsin shore of lake Superior which lies between point Detour and the Montreal river. The shore, in part, is made up of a series of cliffs, either composed of glacial debris or of Potsdam sandstone. In part the shoreline is composed of a series of shore deposits, chiefly in the form of bars, one of which has been thrown across the mouth of Chequamegon bay, forming the longest and most important bar on lake Superior. A group of islands, known as the Apostle islands, lie about Chippewa point, the northern projection of the state. These islands have resulted from the drowning of pre-Glacial valleys. The topography of the mainland is such as existed during pre-Glacial time, but is masked and modified by glacial deposits. The mainland has rugged topography, especially in the interior, at a distance from the lake, and the lake is bordered by a coastal plain a few miles wide, whose simple topography consists of a smooth surface without prominent elevations, in which deep valleys are incised. The topography of the inner Apostle islands is similar to that of the mainland, but the outer islands possess little glacial debris and, in most instances, are mere flat tables of sandstone.

In a general way, the lake level has gradually fallen since the Pleistocene, but this has not been a continuous process, as fluctuations have occurred. At present there is an apparent rise of the lake level, which belief is sustained by two pieces of evidence: (*a*) The lower courses of streams which empty into the lake have estuary features—they are drowned streams—and (*b*) certain shore features, such as bars and spits, are in process of rapid destruction. Apparently these formations were made when the lake was lower, but with its rise they are being destroyed. Wave erosion, especially on the exposed islands, has given rise also to a series of erosion forms, such as caverns, coves, cliffs, and stacks.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 217-270, PLS. 20-25 APRIL 30, 1901

ORIGIN AND STRUCTURE OF THE BASIN RANGES

BY J. E. SPURR

(Read before the Society December 27, 1900)

CONTENTS

Introduction

Investigation of the structure of the desert ranges which lie between the Wasatch and the Sierra and extend southward into California is no easy task. In the past different views have been held, some seeing in them a series of parallel folds in which the anticlines protruding above the surface formed the ranges, while others considered them a series of unfolded blocks, broken by parallel faults, and upheaved along these faults so as to form ridges. Besides these entirely opposed theories a compromise view has been entertained, namely, that the ranges were first folded and subsequently broken into blocks by faults and upheaved into mountains. Even in this compromise there has been great diversity of opinion as to the relative importance of the two chief agents in mountain-building. King,* for example, considered that folding has been most potent, while Russell † believed that the ranges as they now stand are entirely due to faulting and that the faulted blocks have been tilted so that each block is essentially a monoclinal mountain, even when the strata are considerably folded.

In view of all this, the writer proposes to approach the problem without any preconceived theory, to examine the observed facts gathered by himself or by previous investigators, and to deduce from these facts what shall appear to him to be the natural conclusion.

Examination of the Structure of Individual Ranges

RANGES OF NORTHWESTERN UTAH

Tintic range.—This range has been carefully studied by Messrs Tower and Smith.‡ According to these writers the Tintic mountains were up-

---

* Explorations of the Fortieth Parallel, vol. i, Systematic Geology, p. 735.

† Monograph xi, U. S. Geol. Survey, p. 26.

‡ Geology and mining industry of the Tintic district, Nineteenth Ann. Rept. U. S. Geol. Survey, part iii.

lifted in early Mesozoic time; no more accurate determination of the period is available. The uplift was accompanied by marked folding, but little faulting. There is no evidence of a second period of general dynamic action.

The present topography of the range is shown in the sections published* to be entirely due to erosion.

Oquirrh mountains.—The Oquirrh mountains lie immediately north of the Tintic mountains, being separated from them only by 20 miles. These mountains have been described by Mr Gilbert, Mr Emmons, and by the writer. The general interpretation of the structure by the different observers is the same. The range is marked by a series of comparatively close folds, from which the present topographic features have been derived by erosion. Mr Emmons † observes that in the southern portion of the range faulting has been an extremely subordinate phenomenon as compared with plication.

The relation of the topographic forms to the folds shows that the former are due almost entirely to differential erosion. In the Mercur district intrusive sheets of rhyolite (quartz porphyry) have been laid bare, and now, by reason of their greater resistance, constitute hills lying above the more easily eroded limestone.

Promontory range.—The Promontory range lies north of Salt lake and west of the Wasatch mountains, and may be considered as an extension of the Oquirrh range. It has been described by Messrs King and Hague,‡ according to whom the range consists of a central anticlinal fold, with a syncline on each side. The description given indicates deep erosion of the folds to form the present topographic features.

Aqui range.—The Aqui range, as described by King,§ is formed by a great anticlinal fold. In the southern portion of the range this fold is deformed by a powerful fault, which brings the Cambrian rocks against the lower Carboniferous. This fault is depicted upon a section in the atlas accompanying the Fortieth Parallel report. It shows an enormous displacement and a relatively insignificant fault scarp, which has a height of only about one-tenth the throw.

The relation of the amount of displacement to the height of the scarp shows the effects of powerful erosion since the faulting; indeed, the fact that the higher side is made up of quartzite, which is more resistant than the limestone on the lower side, suggests that erosion may be solely responsible for the cliff.

* Ob. cit., plate 77.

† Economic Geology of the Mercur Mining District, Sixteenth Ann. Rept., part ii, p. 361.

‡ Explorations of the Fortieth Parallel, vol. i, p. 736, and vol. ii, p. 420.

§ Op. cit., p. 735.

Ombe mountains.—The Ombe mountains are situated at the extreme western edge of Utah, near the Nevada line. According to Mr King,* the structure in the southern portion is an anticlinal fold, which has a northeast-southwest strike, and thus diverges from the general north-and-south trend of the range. Northward this fold is succeeded, on account of this divergence, by the adjacent synclinal. Still farther northward the entire range has a uniform westerly dip, apparently representing one side of the next anticlinal fold, the other side having been removed by erosion. The east face of this portion of the mountains is a steep escarpment several thousand feet high, which is supposed by Mr King to be a fault scarp. Mr Hague,† who has described in detail the range, and from whose descriptions Mr King's conclusions are presumably drawn, does not mention the fault, although agreeing with the description already given of the folds.

From the above, especially the fact of the ridge being for at least a portion of its length synclinal, it is probable that the mountains, on the whole, are due to erosion.

Résumé of structure of ranges of northwestern Utah.—In summing up the characteristics of the different ranges described, it has been seen that in every case so far as known they owe their principal features to deep, long continued erosion and not primarily to deformation, expressed either by faults or folds. The folds have frequently been so eroded that synclines form the mountain crest; indeed, the synclinal and the anticlinal ranges appear about equally abundant. There are several steep scarps, which have been described as fault scarps, but so far as the writer can make out there is no evidence that a fault exists along them.

RANGES OF NORTHEASTERN NEVADA

Gosiute range.—According to Mr King,‡ the Gosiute range, which lies next west of the Ombe range, consists essentially of a single anticlinal fold. The central portion, however, is a monoclinal ridge, which is a limb of the anticlinal, the other limb having been removed. Mr King remarks that any one passing by this central part might easily be mistaken so far as to suppose the range to be a single monoclinal mass formed by dislocation and tilting.

Since, according to Mr King, the half of the anticlinal fold has not been removed from the central part of the range by faulting, it must have been done by eroson. In the face of erosion so powerful as this we must believe that it has determined the structure of the mountains in general.

* Geologicals Exploration of the Fortieth Parallel, vol. i, p. 736.
† Geologicals Exploration of the Fortieth Parallel, vol. ii, Descriptive Geology, p. 495.
‡ Op. cit., p. 737.

Peoquop range.—Mr King * describes the Peoquop range as showing through most of its extent a monoclinal dip; but in the southern portion of the range this apparent monocline is seen to be really one of the limbs of a distinct syncline, and this syncline gives place to an adjacent anticline in the region of Antelope buttes.

For the same reason as above stated, in the case of the Gosiute mountains, we may infer that the Peoquop range owes its form mainly to long continued erosion.

Humboldt range.—The Humboldt range † has as its principal structural feature a great anticlinal fold, which strikes approximately parallel with the range. The northern portion of the range has a central core of Archean schists and granites, from which the Paleozoic rocks dip away on both sides. From Fremont pass southward to Hastings pass the range is entirely made up of these Paleozoic rocks, which are separated from the Archean area to the north by a great fault at Fremont pass. Mr King states that the eastern face of the range from Fremont pass northward to Eagle lake is the result of a powerful fault by which the dislocated eastern half of the anticlinal fold has sunk out of sight.

The fault which King notes at Fremont pass (and which has also been observed from the base of the range by the present writer) is transverse to the general trend of the mountains or approximately east and west. The vertical displacement is enormous, the Carboniferous and Devonian rocks on the south abutting against the granite and Archean on the north. There is, however, no scarp, only the transverse gap which has been called Fremont pass. The mountains to the north are, to be sure, higher and more rugged than those to the south, but not at all in proportion to the amount of differential uplift, and what difference there is is evidently due to the greater resistance to erosion of the granitic rocks as compared with the softer Paleozoic strata. The writer suspects that a north-and-south fault lies along the west base of the range, by which the Silurian rocks are brought up against the Carboniferous. If this fault exists, the relatively downthrown side forms the mountains, while the upthrown part lies in the valley. Aside from these considerations, the whole rugged and deeply dissected topography bespeaks long continued erosion. The governing anticlinal structure of the range is easily explained, for the core consists of granites and quartzites, which are more resistant than the limestones which overlie, so that the center of the fold when completely denuded still forms the most conspicuous topographical feature and determines the main ridge.

* Ibid.

† King: Op. cit., p. 738.

Piñon range.—The Piñon range, which lies next west from the Humboldt range,* consists in the central portion of a magnificent anticlinal fold, with a curved, although in general north-and-south, axis. The southern termination of the fold is removed by a transverse northeast-and-southwest fault which has faulted down the rocks to the south. Mr King believes that this is the same fault as that which has cut off the end of the Diamond range (which lies southeast of the Piñon range), and has terminated it on the north. North of the Humboldt river, according to Mr King, the same anticlinal fold continues, but is soon cleft by a north-and-south fault, by which the entire eastern portion of the mountains for 40 miles has been dropped out of sight.

Mr Walcott† has made a section across the southern end of the Piñon range, at Ravens nest. The section shows an anticlinal fold cut by two north-and-south faults. One of these faults, in the center of the range, has been estimated by the present writer, from the section given, to have a vertical separation of nearly 4,000 feet, while the other has a vertical separation of about 6,000 feet. Neither of these faults has any influence on the topography except that the first named one has determined a longitudinal shallow valley of erosion.

Considering the displacement which is believed by Mr King to determine the southern end of the range, it is not clear to the writer why the self-same fault is thought here to upthrow the mountains on the north side, while at the northern end of the Diamond range, close by, it is supposed to upthrow an equally high and important range on the south side. In case this is really a single fault, we must explain the opposing phenomena by erosion.

We can only explain a section like that given by Mr Walcott by admitting that the topography is entirely due to erosion; it is not the direct expression of the dislocation. The anticlinal structure in the neighborhood of Pinto peak may be explained like that of the Humboldt range, for here the highly resistant Cambrian quartzites form the center of the anticline and the summit of the range.

Résumé of structure in northeastern Nevada.—The different mountain ranges just described seem in each case to be due essentially to erosion. The crests of the ranges are sometimes eroded synclines, and where the whole of a lofty mountain-mass has a governing anticlinal structure this is generally to be explained by the difference in resistance of the rocks. The faults which have actually been determined are shown in nearly every case to have no primary effect upon the topography, although they sometimes determine gullies or valleys by reason of their

* Ibid.

† Monograph xx, U. S. Geol. Survey, p. 201.

being zones of weakness, and hence easily eroded. In this region, as in that of northwestern Utah, if the mountain ranges are mainly due to erosion, it follows that the intervening valleys originated in the same way.

RANGES OF NORTHWESTERN NEVADA

Havallah range.—The northern portion of the Havallah range* is essentially an anticlinal fold of Triassic rocks. Adjacent to this anticline is a parallel syncline, which lies to the west of the main mountain range. To the east of the main ridge is a syncline, which forms a subordinate ridge between Iron point and Golconda, on the Central Pacific railroad. The northern end of the range is supposed by Mr King to be determined by a transverse fault.

Mr Hague, who has written a more detailed description of the range, does not mention the fault, but gives more information about the folding. The highest portion of the mountains, which is the center of the anticline, consists of dense, tough quartzites, while the overlying strata on the flanks are interstratified sandstones, slates, and shales. Along the very axis of the anticline is a deep canyon.† Southward from here, at Bardmass pass, the governing influence of the underlying rigid quartzite being no longer felt on account of its lying so far below the surface, the range consists of two gentle folds, an anticlinal and a synclinal, the latter forming most of the mountains, while the axis of the anticline lies along the eastern foothills.‡

The synclinal ridges described are evidence of powerful erosion, while the hard resistant core of the chief anticlinal fold explains the origin of this ridge also as an erosive feature, in the same way as in the East Humboldt and Piñon ranges.

Pah Ute range.—The Pah Ute range § has also a governing anticlinal fold. A series of chiefly north-and-south faults has confused the structure. Mr King's descriptions imply that these faults have a direct influence on the topography.

Mr Hague ‖ describes the central core of the mountains as made up of granite and granitoid rocks, these being overlain by Triassic quartzites, and these by limestones and shales.

That erosion has actually been very active in this range is shown by the enormous thickness of rocks (15,000 to 17,000 feet at least ¶) which has been stripped off from the underlying basement.

* King: Op. cit., p. 741.
† Fortieth Parallel, Descriptive Geology, vol. ii, p. 681.
‡ Op. cit., p. 683.
§ King: Ibid.
‖ Op. cit., p. 689.
¶ King: Op. cit., p. 277.

West Humboldt range.—The West Humboldt range,* which is next west of the Pah Ute, has a main anticlinal fold, which trends diagonally across the topographic axis.

Mr Hague † mentions two faults in this range, one along the eastern side of the range, the other crossing it in a northwest-southeast direction west of Buffalo peak. The existence of the latter fault is evident from an inspection of the map accompanying the Fortieth Parallel report. Judging from this, the displacement seems to be a downthrow on the south side, bringing the Star Peak Triassic down against the underlying Koipato Triassic—a movement amounting to several thousand feet. The fault line lies in a valley, from which the mountains rise on the southeast side about 2,700 feet; on the northeast side about 4,200 feet. The southeast or downthrown side of this valley is decidedly the steeper.

In this case we have an actually determined heavy fault, which is not marked by a scarp, but by a transverse valley, where erosion has excavated at least 2,700 feet deeper than in the rocks on each side; nor is this more than a fraction of the total erosion, for while the valley was being formed the mountains have also been steadily wearing down, only more slowly, on account of the zone of greater weakness along the fault. On the northeast all the Star Peak Triassic (which is now found on the other side of the fault, and so must have been on this side, too, before the dislocation) has been worn away, leaving bare the underlying Koipato. As the Star Peak group has an estimated thickness of 10,000 feet,‡ the total erosion since the faulting has at some points exceeded two vertical miles. The present greater elevation of the mountains in the upthrown or northeast side of the fault is probably due to the greater resistance to erosion of the Koipato quartzites, as compared with the softer rocks on the south. This same resistant formation has been noted as determining topographic eminences in the Havallah range.

In the West Humboldt range, therefore, there is evidence of erosion powerful enough to have determined the topography and the range itself, and in the one case where we are sure of our premises, erosion has long since overcome all direct effects of deformation on the surface, if indeed there ever were any.

Résumé of structure of northwestern Nevada.—Our knowledge of the ranges of northwestern Nevada is comparatively slight, since in this region the volcanic rocks are so abundant that nearly everywhere they mask the structure, which is itself rather complicated, with folds often diagonal

* King: Op. cit., p. 742.
† Op. cit., p. 736.
‡ King: Op. cit., p. 277.

to the mountain ridges and with faults. From what we can learn of the structure, where the stratified rocks are exposed, it is apparent that erosion has operated very powerfully. We find synclinal ridges and anticlinal ridges, with a hard resistant rock at the core, and faults along which deep valleys have been excavated. On the other hand, we appear to have no sufficient evidence of any feature of relief being due directly to deformation. Some supposed faults have been described in terms implying this direct relation, but it is not clear from the descriptions that these faults actually exist. Indeed, as in so many other cases, the existence of the fault seems often to have been assumed from the presence of a scarp. We must conclude, therefore, that the ranges of northwestern Nevada, in so far as we have direct evidence on the questions of their structure and origin, are due chiefly to erosion.

RANGES OF EASTERN CENTRAL NEVADA

Antelope range.—The Antelope mountains, which lie between the northern extension of the Snake range and a portion of the Schell Creek range. are for the most part volcanic. In the southeastern portion, however, are Silurian and Devonian rocks. The attitude of the rocks here, as compared with that of the same rocks on the other side of Antelope valley, goes to show that this valley is anticlinal. It is therefore probably one of erosion, and the same inference applies to the Paleozoic foundation of the Antelope range.

Schell Creek and Highland ranges.—The Schell creek range contains a number of adjacent anticlines and synclines, which often trend somewhat obliquely with the range. East of Ely there is a longitudinal valley eroded along the axis of an anticlinal fold; farther south this anticlinal fold seems to cross from the Schell Creek to the Egan range. There are probably some transverse faults.

The Highland range has a system of petty folds, some longitudinal and some transverse. There are also a number of transverse faults, some of which have vertical displacements of several thousand feet. In the mining camp of Pioche there is exposed by mining a system of faults, which is probably a good index to the less observed faults of the range. The faults here are numerous and belong to a north-and-south and an east-and-west system. The main one runs east and west, and along it the relatively downthrown side forms the highest hills, being indeed marked by a continuous cliff, which but for the fact above stated might be considered a typical fault-scarp. The massive metamorphosed limestone has resisted erosion better than the brittle, easily frost-fractured quartzite on the upthrown side. Other faults are marked by gullies.

The less definitely determined cross-faults of the main range are also typically marked by transverse gaps and not by scarps.

The conclusion is natural that in these ranges deformation of the topography by faults and folds has been mainly mastered and obliterated by differential erosion, to which is chiefly due the present relief.

Snake range.—In the Snake range the structure is, in general, anticlinal. At Wheeler or Jeff Davis peak it is quaquaversal; at Uiyabi pass anticlinal. The name Kern mountains is applied to a northwest-and-southeast ridge, transverse to the general trend of the range; this range seems also anticlinal. In the main range the eastern half of the anticline has often been removed, apparently by erosion.

The range is one of considerable faulting. North of Wheeler peak are two east-and-west faults, and north of the Kern mountains is a northwest-and-southeast fault. The two faults north of Wheeler peak have given rise to a transverse gap across the range at this point. One of the faults shows an obscure reversed scarp on the downthrown side, the other on the upthrown side. This shows that the first surely, and perhaps both, are due to erosion. The fault north of the Kern mountains lies in and has probably determined Pleasant valley.

The massive character of the rocks in this range renders the differential work of erosion comparatively slight, but various phenomena, such as the above-mentioned relation of the faults to the topography, show that general erosion has been long and powerful. This is also pointed out by the fact that quite ordinary springs have been able to excavate deep and picturesque canyons.

Long Valley range.—This range consists of low ridges of Carboniferous strata, which lie between the Egan range and the northern extension of the White Pine range. The main ridge has an apparent monoclinal structure. This, however, is really the east side of an anticline whose westerly side is exposed in the next ridge westward, the intervening valley being formed by erosion along the axis of the fold. This fold is succeeded farther east by a syncline, a second anticline, and a second syncline.

Anticlinal valleys and the synclinal or monoclinal ridges are predominant. The range is, therefore, one of erosion.

White Pine range.—In general the White Pine range is made up of synclinal ridges and anticlinal valleys. The main ridge from Hamilton northward is a persistent syncline. In the immediate vicinity of Hamilton, however, in the White Pine mining district, there are certain faults which appear to be so recent and to have such intimate connection with the topography that it seems likely they have actually displaced the surface and that the break has not yet been disguised by erosion. The

minor anticlinal fold of Treasure hill evidently belongs to the same recent period of deformation, and also determines directly the topography. The faults in this district are north-and-south, east-and-west, and oblique, one noted being northwest-and-southeast.

Quinn Canyon and Grant ranges.—The Grant range is a southern extension of the White Pine range, and at its own southern end is directly connected with the Quinn Canyon mountains. These ranges are interesting because they have on both sides comparatively steep scarps, which are by no means so common in the Great basin as has been believed.

The Quinn Canyon range consists at its northern end of a broad shallow syncline, while the anticline adjacent on the east lies in the valley separating these mountains from the Grant range. The Grant range at this point is also essentially synclinal, but the anticline which lies east of this second syncline is often exposed in its eastern face. Thus there are in general two adjoining synclinal ranges, separated by an anticlinal valley. On the east face of the Grant range and on the west face of the Quinn Canyon range, moreover, the structure is anticlinal, and appears to determine the limit of the mountains (see plate 25, figure 1).

The north end of the Quinn Canyon range is along a fault, but in this case the relatively upthrust rocks to the north constitute the foothills, while the downthrust Silurian rocks on the south form an abrupt mountain scarp.

It is plain, therefore, that in these ranges the chief topography is due to erosion, which has worked so powerfully as to overbalance any deformation. Some of the scarps have no connection with faults; for example, in the case of those north-and-south scarps which form the east-and-west faces of the ranges it has been demonstrated that no great governing faults exist. In the case of the north end of the Quinn Canyon range, which is along an east-and-west fault, the fact above stated shows that the steep scarp is not directly due to faulting, being indeed the reverse of what it would be if this were the case, and must be directly due to erosion. As a matter of fact, the scarps which bound these mountains are no more rugged than the interior topography. The canyons are deep, with precipitous walls, and bear witness to the localized or basal erosion which operates so powerfully, as contrasted with general erosion, in an arid and mountainous region.

Diamond range.—The Diamond range consists chiefly of an anticlinal fold with an attendant syncline. The main axis of the range cuts across the strike of these folds in their minor deviations, but is in general parallel to it. In the Eureka district there is a condition often found in mining regions, where complicated topography is dependent upon increased complications of structure. Such topography may be due directly

to deformation or, more often, directly to erosion acting upon the folded and faulted rocks. In this place it is plainly due to the latter process. There are a series of faults which strike in general northwest and southeast, transverse to the trend of the mountains at this point. These faults are not directly expressed in the topography, for sometimes the downthrown side appears as a scarp and sometimes the upthrown, depending upon the relative resistance of the beds, while more frequently there is no effect upon the topography, except, perhaps, the formation of a gulch.* Therefore the Diamond range is, so far as known, one of erosion.

Egan range.—The Egan range consists of a number of adjacent folds which have been well dissected by erosion. In the extreme northern end the prevailing structure is anticlinal, and farther south it changes to synclinal. At the southern end there is an alternating series of open folds which are not expressed in the topography. Here the writer suspected a number of east-and-west faults along lines marked by deep transverse gaps, but not by scarps.

In general, therefore, this range seems to be one of erosion.

Pancake range.—The faulted syncline of Newark mountain and the Alhambra hills, which is found in the Eureka district of the Diamond range, is continued southeast across the intervening valley to the Pancake range.

At the south end of the Pancake range, at Twin springs, a number of north-and-south faults were observed in the Pliocene sediments. Some of these faults have a vertical separation of several hundred feet and are marked by gullies, but not by scarps.

The Pancake range, therefore, is largely one of erosion. To this must be added vulcanism, for a large part of it is built up of lava.

Hot Creek range.—At Hot creek the range is essentially a faulted anticline, supported on the west by a heavy buttress of rhyolite, which farther north envelopes and hides the Paleozoic core. Observed faults run north and south, while others, strongly suspected, are east and west. Some of the north-south faults are marked by gulches and some by normal scarps (see plate 25, figure 5).

The anticlinal ridge with no core of relatively great resistance, and the normal fault-scarps suggest strongly the theory of origin by direct deformation. The question, at first puzzling, as to why erosion has been so comparatively impotent here finds a plausible answer when we consider that the lavas must have originally covered this portion of the range as they do now a few miles farther north. This covering must have protected the Paleozoic strata from erosion; but in the lava buttress

* See Atlas, Monograph xx, U. S. Geol. Survey.

above referred to transverse gaps several thousand feet deep, with tributary gulches, have been excavated.

Résumé of structure of eastern central Nevada.—In every case which has been described, except the last, the ranges appear to have been formed chiefly by erosion. Synclinal ridges are frequent and faults not especially abundant. When faults have been found to be present they have no primary effect upon the topography, except in rare cases. In general, indeed, they stand as witnesses of the greater power of erosion by their lack of scarps, by the reversed scarps (that is, scarps where the eminence is on the downthrown side of the fault), or by the deep gulches which have been eroded along them. The Tertiary volcanic rocks which are found in this region also show very deep erosion.

The Hot Creek range belongs to an exceptional type, whose deformation features have apparently not been overbalanced by erosion, and this is very likely due to protection by overlying lavas, which have themselves suffered deep erosion.

RANGES OF WESTERN CENTRAL NEVADA

Toquima range.—Most of the Toquima range consists of Tertiary volcanics, eroded so profoundly that in places (as near Belmont) dikes, which were, perhaps, the feeders, are exposed. The stratified rocks, which lie near Belmont and south of it, appear to be bent into an anticlinal fold, which trends north and south. Along the axis of this is a minor valley, probably one of erosion.

We may conclude that this range owes its origin to differential erosion plus vulcanism.

Toyabe range.—This range lies immediately west of the Toquima range. Its southern portion is entirely buried beneath immense flows of rhyolite. Farther north * the structure is a distinct anticlinal fold, running nearly north and south. A little south of latitude 40 degrees this fold is cut by an east-and-west fault. The axis of the anticlinal, according to Mr Emmons,† has suffered from a pressure coming from a direction different from that which originally formed it, so that it is curved and the folds distorted. This deformation of the original north-and-south fold is probably connected with the east-and-west faulting. At Ophir canyon Mr Emmons noted a syncline adjacent and to the east of the main anticline.

The anticlinal structure is explained when we find that the rock exposed along the axis of the fold is a heavy quartzite, more resistant than the limestone which overlies. This structure, then, instead of indicating

* King: Geological Explorations of the Fortieth Parallel, vol. i, p. 740.

† Geological Explorations of the Fortieth Parallel, vol. iii, Mining Industry, p. 326.

that the range is directly due to deformation, is in this case rather an evidence of deep erosion.

Walker River range.—As the Walker River range is chiefly composed of igneous rocks, it is difficult to draw such reliable conclusions as to its structure and origin as in the case of the range made up of stratified rocks. This range on its eastern side has a steep scarp, resembling in miniature the eastern scarp of the Sierras. At the foot of this is Walker lake. The scarp has been explained by Professor Russell as having been formed directly * by a fault. We are, however, without convincing evidence as to whether the scarp is a simple erosion scarp, a simple fault-scarp, or an erosion fault-scarp (the latter term signifying a scarp formed by erosion along a fault-plane), for in the first place we have no proof of the fault's existence, and in the second place, supposing the fault to exist, we have no proof of its relation to the origin of the scarp. On the other hand, the basal erosion at the foot of the scarp is strongly marked. As has been stated, Walker lake and Walker river lie here, and in former times the lake was more extensive, being an arm of the greater lake Lahontan. The erosive action of the present lake is probably not inconsiderable, and that of the ancient lake is abundantly proved by the high and deep terraces, which are at least several hundred feet high and 1 or 2 miles in width, and are composed of great angular and subangular boulders derived from the mountain above. The abstraction of so much material from the base of the mountains would have perhaps formed the scarp without any other agency.

Pinenut and Virginia ranges and the eastern face of the Sierras.—What has been said concerning the Walker River range applies also to these ranges, which have similar characteristics. They are chiefly made up of igneous rocks, and show abrupt east-facing scarps, while the west face is generally but not always of gentler slope In each range also the steep eastern side is composed chiefly of granular rocks, while the western side is typically covered by volcanics. This of itself is not a clue to the origin of the mountains, for such would be the case whether the scarp was formed by erosion or by faulting. There are, however, evidences of north-and-south lines of fracture, which are very likely also lines of displacement. Springs break out along these, from which it happens that they are also lines of erosion, producing within the ranges longitudinal gulches. It is very likely that the steep eastern scarps are marked by similar displacements, which may be greater than ordinary. On account of the considerable erosion which is shown throughout this district, however, it seems more probable that the mountain fronts are not simple

* Monograph xi, U. S. Geol. Survey

fault-scarps, but are either simple erosion scarps or erosion fault-scarps.* The rapidity with which the Carson river has eroded its deep canyon between Carson and Dayton since the disappearance of the late Pliocene lake Shoshone and the deep and rugged transverse canyons in the Virginia range all militate against the belief that faulting should have been rapid enough to have outstripped on so large a scale the erosion.

While acknowledging, then, that it will require more careful study to finally decide the origin of these volcanic ranges, we may yet point out that the fault theory has only the value of an hypothesis, and at the same time we may indicate the claims of an antagonistic hypothesis, that of basal erosion.

Although the climate is arid, this region, compared with the most of the Great basin, is well watered, for it receives streams which rise in the moister Sierras. In earlier times the region was occupied by fiorded lakes which fretted their mountain shores and wore them back. On account of the general westerly slope of the whole western part of the Great basin these lakes were deeper, and consequently possessed more eroding and transporting power on the western side of the valleys; and when they shrank so that they could not occupy whole valleys, they rested against the eastern face of the ranges. Lake Lahontan washed the eastern side of the Walker River range, but did not touch the western; it lay at the eastern base also of the range next west, but did not approach its western side.† Hence it is, perhaps, that the ranges have a tendency to a steep scarp on the east more than on the west. In places, however, we find they have worn back so as to present a steep scarp on both east and west. This is true of the Pinenut range just east of Dayton; at this point lake Lahontan washed both sides of the range.‡ The Sierra Nevada, since it formed the final barrier to all these lakes, was naturally attacked only on one side. §

Excelsior range.—The Excelsior range is made up partly of igneous rock and partly of a series of folded limestones, shales, and sandstones. In the limestones fossils were found which are regarded as early Tertiary, while the sandstones (judging from their lithology alone) appear more nearly referable to the Jurassic or Triassic. These sedimentary rocks have been folded and eroded so as to outcrop in synclinal hills and anticlinal valleys. The volcanic rocks, which are of later date, have also been deeply worn down. The axis of the main fold is east and west.

The Excelsior mountains, therefore, were folded during Tertiary time;

---

* See p. 259.

† Russell: Map, Monograph xi, U. S. Geol. Survey.

‡ Russell: Ibid.

§ The question of the existence, number, and nature of the Tertiary lakes of the Great basin, although demanding discussion (see W. M. Davis, Proc. Am. Acad. Arts and Sciences, vol. xxxv, no. 17, March, 1900), can not suitably be dwelt on in this paper.

subsequently covered by lavas; and deeply worn down by general erosion, which produced anticlinal valleys and synclinal hills.

Résumé of ranges of western central Nevada.—The abundance of volcanic rock in this region makes the determination of the origin of the ranges still more uncertain than usual. The high degree of folding of the early Tertiaries (which are not found farther east) shows that the last epoch of mountain-making was Tertiary. We can not be sure how long this period of disturbance lasted, nor have we any reason for believing that it is yet entirely finished. But the period of greatest activity closed before the epoch of the late Pliocene early Pleistocene lake Shoshone, whose deposits are generally horizontal. In certain places, however, the deposits of this lake have probably been uplifted a thousand feet or more in a gentle swell, showing more recent Pleistocene movement. Whether any of the pronounced folds and faults have outstripped erosion so as to preserve their direct expression in the topography we can not be certain, though it appears possible. This region lies in an orographic zone, whose trend is defined by the direction of its mountain ranges and by their parallelism to the eastern front of the Sierra; farther south this zone includes the Death Valley region, where late Tertiary and Pleistocene deformation certainly occurred, and, apparently, directly created mountains and valleys.* Nevertheless, where we have opportunity to investigate the amount of erosion in western central Nevada, as in the case of the Excelsior mountains, we find it has been sufficient to overbalance the effects of the Tertiary folding. Therefore we must conclude that the effects of erosion are more important than those of direct deformation, though the latter agency may be a greater factor than we are yet aware in producing ranges and minor topography.

RANGES OF SOUTHERN NEVADA

Virgin range.—The Virgin range constitutes the last of the high mountain ranges to the east and faces the Colorado plateau. According to Marvine,† the east face of the range coincides with a fault which appears to be one of the Colorado Plateau system, for Dutton ‡ describes on the eastern edge of the Grand wash (which lies directly east of the Virgin range) a second fault, by which the country to the east is upheaved between six and seven thousand feet. Marvine states that the main fold of the range is an anticline. Toward the south the folding dies out, and the rocks become horizontal in the Colorado canyon.

If, as appears from the reports, the eastern face of the range is a simple

* See p. 239.

* U. S. Geol. Survey West of Hundredth Meridian, vol. iii, Geology, p. 194.

† Second Ann. Rept. U. S. Geol. Survey, p. 126.

fault-scarp, it seems likely that the fold may also be comparatively recent. Erosion has undoubtedly been active, but, since it apparently has not yet overcome deformation, we may consider the range as being due primarily to the latter, with the minor topography determined by erosion.

Mormon range.—The Mormon range is anticlinal in structure. Along the crest of the anticline, in the Carboniferous limestones, a notch has been eroded, which is, however, not yet deep enough to form an interior valley. The slight development of this valley is proof that erosion has not yet been able to complete the work which it has undertaken, that of overcoming the direct effects of deformation on the topography. The folding must then be comparatively recent. The earlier Tertiaries which lie at the foot of the mountains are conformable with the Paleozoic rocks and have been upturned with them. The date of the general disturbance, therefore, can hardly be earlier than Middle Tertiary. Moreover, the late tertiary sediments also, which in some cases may even be early Pleistocene, have been in places folded and faulted. These faults are comparatively slight and of different ages, as is shown by the fact that some are not expressed in the topography, erosion having overcome their effects, while others, more recent, have faulted the present surface equally with the underlying rocks (see plate 25, figure 4).

We may conclude that the origin of these mountains is like that of the Virgin range; that they are primarily due to comparatively late folding, and probably in a less degree to faulting, while in the minor features of topography erosion has already accomplished considerable work.

Meadow Valley range.—The north end of this range is largely volcanic, but in places, as at Delamar,* the heavy Cambrian quartzites and limestones, which extend south from the Highland range, are exposed. South of Delamar stratified rocks are the rule, and at the southern end the range is entirely made up of Carboniferous limestones. In a section across the range at this point, following the valley of Muddy creek, no less than six parallel and adjacent open folds were observed. The synclines generally form ridges, the anticlines longitudinal depressions or valleys. North of Muddy creek the central ridge is synclinal, while south from it there are two principal synclinal ridges, with an intervening anticlinal valley. The faces of the ridges are often steep, and might be considered by casual observers to be fault-scarps, yet there is no known evidence of faulting along them.

At Delamar Mr Emmons has observed a heavy east-west fault in the Cambrian strata, having a downthrow on the north of probably several

* Verbal communication by Mr Emmons.

thousand feet. This fault has determined a minor valley, but has no primary effect on the topography.

The Meadow Valley range, therefore, is a typical example of mountains formed almost entirely by erosion, which has carved them out of a series of gently folded and probably little-faulted strata.

Las Vegas range.—This irregular group of mountains lies close to the Meadow Valley range, and indeed passes into it at one point without any intervening valley. It has in general a northwest trend, but there is a branching ridge running due north and forming a V with the main mass. Since this ridge, which is very high and bold, was not represented on the maps, the writer called it, for convenience of designation, the New mountains.

The general folding in the Las Vegas mountains is a rough, shallow, northeast-and-southwest-striking syncline, which is succeeded on the west by a much sharper anticline, along which the narrow valley separating the Desert and Las Vegas ranges has been eroded. The New mountains seem to be separated from the westernmost ridge of the Meadow Valley range by an anticlinal valley, which at its southern end gives way to mountains uniting the two ranges.

The rocks of the range consist of heavy limestones, ranging in age from Cambrian to Carboniferous. North of Mormon wells there appears to be a heavy east-and-west fault, which has brought the Carboniferous limestone into contact with the Cambrian. The vertical displacement must be several thousand feet, but it is marked by no scarp whatever, although the minor topography changes, owing to the different character of the two limestones. Bold scarps are frequent and even characteristic in these mountains, but so far as could be seen they are not caused by faults.

Recapitulating, the mountains possess synclinal ridges and anticlinal valleys and have a heavy east-and-west fault which does not affect the topography. They are, therefore, largely due to erosion. Since the trend of the main fold is oblique to that of the mountains, the configuration has not been entirely controlled by the structure. Las Vegas valley, which lies on the west side of the range and separates it from the Spring Mountain range, is wide and clear cut and runs at nearly right angles to the folding. Topographically this valley is a branch of the valley of the Colorado river, although actually it carries no drainage. If the climate should become moister, however, a stream would at once establish itself, and the aspect of the valley suggests that at a former period it was carved out in this way.

Spring Mountain range.—The Spring Mountain range shows a shallow wrinkled syncline, with a northeast-and-southwest axis. This belongs to the same series as the folds of the Las Vegas range, which are prob-

ably persistent across Las Vegas valley. Transverse to this is a gentle anticline, from whose apex the rocks in the center of the syncline, which should lie flat, dip north and south. In the northern portion of the range two heavy east-and-west faults were noted. One of these has an estimated displacement of 1,000 feet and the other of several thousand feet. The first is accompanied by a slight normal scarp, which, however, is only an exceedingly small fraction of the vertical displacement, and is indeed caused by the superior hardness of the upthrust Cambrian quartzite. It is, therefore, a simple erosion fault scarp. The second fault has left no mark on the topography, since the Middle Cambrian limestone to the north has about the same resistance to erosion as the Upper Carboniferous on the south (see plate 25, figures 2 and 3).

The general synclinal structure, and the powerful faults without attendant displacement of the surface, bear evidence to long continued erosion, to which the range seems to be due. The transverse anticlinal fold recalls the anticlinal structure of the Kingston range, which lies next west and which is probably of more recent origin than the synclinal ridges just described. The anticlinal swell in the Spring Mountain range, therefore, is perhaps of a later origin than the syncline, and the arching of the mountains along it may be directly due to deformation and not to differential erosion. This last peculiarity is the ruling feature of the district which lies west of here, where many of the mountains are very likely due to uplift, so that this range apparently lies on the boundary between a region of older and a region of newer folding, and may have experienced both. According to this the range is due to (1) erosion plus (2) simple deformation.

Pahroc, Hyko, and Pahranagat ranges.—The Pahroc range, as seen from the north by the writer, seems to be anticlinal.

The Hyko and Pahranagat ranges, according to Mr Gilbert, show no folding, but a series of north-and-south faults and an east-and-west fault. The topography of these ranges and of the neighboring Timpahute range as well, is explained as chiefly due to this system of faulting, which has produced parallel ridges by the downthrow of successive blocks.

Mr Gilbert has drawn sections of the Pahranagat and Timpahute ranges.* In the case of the latter range he shows a number of faults outcropping in the bottom of a wide and shallow interior valley, which he states has been eroded out of soft shales lying between more resistant quartzite on the west and limestone on the east. The section shows nowhere an example of topography derived directly from structure;

* Surveys West of the Hundredth Meridian, vol. iii, Geology, p. 38.

there are no simple fault-scarps. On the contrary, the faults indicated either have no expression at the surface or have determined gulches, showing in both cases mastery of dislocation by erosion.

Nevertheless, Mr Gilbert is inclined to consider that the range in general is due to dislocation and uplift and not to erosion.* He writes:

> "The valley in the range, due to the occurrence of soft shales between harder beds, opens to the south, and is deepening very slowly, because it is little elevated above the plain. If the depression occupied by the gravels of the plains had itself been not only emptied, but excavated, it is inconceivable that the shale in the mountain should have escaped deep erosion."

The detritus, in places several thousand feet thick,† which fills the broad valleys between the ranges indicates of itself the long erosion which has proved sufficient to overcome all primary deformation in the interior of the mountains. However, this erosion has been very largely under arid conditions, which differ from those of moister climates.

In the desert erosion may be divided into two kinds. The first kind is active where there are local permanent water bodies, usually derived from some source outside the district. Such is the Colorado river, which runs through an arid plateau and derives its supplies chiefly from the distant Rocky mountains. These exogenous water bodies produce topographic forms whose importance is greatly increased by the relative inactivity of erosion on other parts of the surface. Thus by the Colorado river the stupendous Grand canyon has been cut, and in many of the Basin ranges springs of moderate volume have excavated deep and picturesque gorges. This kind of erosion may be called *special* or *basal*.

The second kind operates where the extraneous factor is absent. Here the moisture is confined to occasional cloudbursts, and its effect as an agency of erosion is equaled or exceeded by disintegration, gravity, and eolian action. The result is that in the lower valleys leveling, instead of dissection, is brought about, and in the higher ones dissection is much less marked than in moister regions. So the shallow valley which lies within the Timpahute range, and was carved during a period of moister climate, is probably not being deepened, but indeed is being made relatively shallower by the degradation of the higher mountains which form its sides.

The writer, therefore, sees as yet no evidence that simple deformation has played a part in creating these mountains, and believes that by far the most important agency in producing them was erosion.

---

* Op. cit., p. 42.

† See Davis, Physical Geography, p. 309.

Worthington mountain.—This is a single mountain, and would not be mentioned except that it has been described by Mr Gilbert.* It lies northwest of the Pahranagat range, with which it is connected by a series of hills. Mr Gilbert, apparently viewing it from its southern end, sketched the structure as nearly horizontal. The mountain rises with the ordinary degree of declivity from the desert valleys at its base, and its slopes were believed by Mr Gilbert to indicate faults. He says:

"I can conceive of no erosion that should have left this thin segment as the remnant of an inclined table or of a fold. Its narrowness, its straightness, and its isolation marked it as a mass of strata thrust upward between two faults, of which the companion parts lie beneath the debris at its feet."

The range was observed by the present writer at its northern end, and a view was also obtained southward along its eastern face. The dip, which at the southern end is nearly horizontal, with a slight easterly inclination, becomes westerly farther north and increases gradually until at the northern end, some 14 or 15 miles from the southern end, it reaches 30 degrees and follows the general surface slope. Therefore Mr Gilbert's reasons for assuming faults on both sides do not apply to the northern end, for, seen from the north, the mountain might be explained by followers of the fault hypothesis as a faulted monocline; but the change in dip suggests that the mountain is part of an anticlinal fold. It has been observed by the writer, and previously by Mr Clarence King,† that many of the monoclinal ridges of the Great basin belong to folds from which the other parts have been removed by erosion, and that very often, by following a range, a portion may be reached where the whole fold is shown.

Résumé of ranges of southern Nevada.—The known evidence indicates that the ranges of central southern Nevada are almost entirely due to erosion, which has worked on a series of folded and faulted rocks so strongly as to overcome any direct effects of deformation on the surface. But on the margins of the region, in the Mormon range, and possibly in the Spring Mountain range, there are features of relief which appear to be primarily due to deformation, expressed chiefly by folding and to a less degree by faulting. The deformation which is expressed in the topography is evidently younger than that which has been subdued.

RANGES OF CALIFORNIA ADJACENT TO SOUTHERN NEVADA

White Mountain range.—The White Mountain range shows several adjacent folds broken by faults.‡ The chief fold, according to Mr Walcott,

* Surveys West of the Hundredth Meridian, vol. iii, Geology, p. 37.

† Geological Explorations of the Fortieth Parallel, vol. i, p. 737, etc.

‡ G. K. Gilbert: Wheeler Surveys West of the Hundredth Meridian, vol. iii, Geology, p. 34. C. D. Walcott: Am. Jour. Sci., 3d ser., vol. xliv, 1895, p. 169.

is a closely compressed syncline overthrown toward the east. Mr Walcott's section shows, in general, synclinal ridges and anticlinal valleys, and both in his section and in Mr Gilbert's the faults have no expression in the topography.

Mr Walcott has pointed out that the structure of this range is of the Appalachian type, and from the facts given we must conclude that the relief is due to long continued erosion.

Grapevine and Funeral ranges.—The Funeral mountains are the southern continuation of the Grapevine range, but are not so high. There is no interval between the two, but a steep mountain scarp on the south side of Pyramid peak serves as a boundary. To the north of this line the Grapevine range is made up of Paleozoic strata, and to the south the Funeral mountains consist of Tertiary sediments and volcanics.

At Boundary canyon the Grapevine range consists essentially of an anticline* cut by longitudinal and transverse faults, while at Furnace creek, which is near the above-defined line between the mountain groups, the writer observed two anticlinal folds with an intervening syncline. Near the latter place the topography seems to have been, to a large extent, directly determined by the folding, so closely does one correspond to the other. This correspondence is more striking in the Funeral range proper. Here Furnace Creek valley follows along the bottom of a curving syncline, and on both sides are anticlinal ridges whose slope is the same as the dip of the constituent beds. Of these ridges, that on the west, sometimes called Black mountains, is most important. The rocks of this dip down into Death valley, which appears to be a synclinal trough. In these folds has been involved not only the whole Tertiary section, but also the overlying olivine-basalt, which, by correlation with other occurrences, may be tentatively classed as early Pleistocene†; the movement must therefore have been prolonged into very recent times. The structure recalls the diagram of the Jura mountains given by Davis.‡

But previous to this recent folding, as the writer has ascertained, there existed prominent mountains, representing the present Grapevine range, whose rocks were little folded and whose relief must have been due to pre-Tertiary erosion; and to these earlier mountains the Grapevine range owes much of its relief and its elevation above the Funeral range. Thus, while the Funeral mountains may be said to be due entirely to deformation, since folds and probably faults are directly expressed at the surface, the Grapevine range owes its origin to simple erosion plus simple deformation.

*G. W. Gilbert: Wheeler Surveys West of the Hundredth Meridian, vol. iii, p. 33.

†J. E. Spurr: Jour. Geol., vol. viii, no. 7, p. 636.

‡Physical Geography, Boston, 1899, p. 168.

Kingston range.—The Kingston range, as viewed from the east and north, appears to consist chiefly of a simple anticlinal fold in Paleozoic limestones. Stuart valley, which lies east of its northern end, seems synclinal. No faults were observed. Since the range lies next east from the recently folded Funeral mountains, the structure suggests that it also has originated by direct deformation.

Mojave desert.—Southward from the Kingston and Funeral ranges stretches the Mojave desert, where upturned beds, like those of the Funeral range, occur. In the Calico mountains, near Daggett,* these folded Tertiaries have been eroded to anticlinal valleys and synclinal ridges, and there is a heavy fault which is not expressed in the topography. These hills are therefore due to differential erosion. Either, therefore, the uplift which affected them was earlier than that which folded the Funeral Mountain region, or, granting that the disturbance was simultaneous in both regions, it follows that for some reason erosion has outstripped deformation in one locality and has been distanced by it in the other. If the uplifts were indeed contemporaneous, erosion must have been more active in the Calico mountains than in the Funeral range, or deformation must have been more sluggish. Considering the first alternative, we find that both regions possess the same intensely arid climate, so that differences in rapidity of erosion, involving differences in precipitation, can hardly be postulated. Thus we are thrown back on the second assumption. As a matter of fact, the folds shown by Mr Storms are petty compared with the grand flexures of the Funeral range.

COLORADO PLATEAU

Eastward from the Basin ranges lies the Colorado plateau, where the strata down into the Cambrian are level,† with the exception of occasional simple swells which seem to have been contemporaneous with periods of folding in the Basin ranges or the Wasatch.‡ The chief deformation has been accomplished by a series of north-and-south faults, which have generally expressed themselves directly in the topography—that is to say, they are marked by simple fault-scarps.§ These faults

* W. H. Storms: Eleventh Rept. Cal. State Mining Bureau, 1892, p. 347.

† G. K. Gilbert: U. S. Geol. Survey West of the Hundredth Meridian, vol. iii, Geology, p. 196.

C. E. Dutton: Tertiary History of the Grand Canyon District, Monograph ii, U. S. Geol. Survey, with atlas.

C. D. Walcott: Am. Jour. Sci., 3d ser., vol. xxxi, p. 437.

‡ C. E. Dutton: Second Ann. Rept. U. S. Geol. Survey, p. 65.

§ J. W. Powell: Exploration of the Colorado, p. 182 et seq.

C. E. Dutton: Second Ann. Rept. U. S. Geol. Survey, pp. 117, 118, 124, 125, 126, 133, etc.

G. K. Gilbert: U. S. Geol. Survey West of the Hundredth Meridian, vol. iii, pp. 43–57; yet for an exception to the rule see Gilbert's last section on p. 50, where the scarp is on the *downthrown* side of the fault, constituting a typical reversed erosion fault-scarp (see p. 259, this paper).

are recent, as is shown by the fact of their expression in the topography and by their cutting the basalts, which are probably early Pleistocene.*

General Conclusions as to Origin of Basin Ranges of Nevada and California

The process of mountain-building in this region has been complicated, so it is to be expected that when the details shall have been more closely studied many types of ranges will be found. But at present we can hardly distinguish more than two—those formed chiefly by erosion and those due directly to deformation. To the first class seem to belong most of the mountains of the region. To the second class probably belong part of the ranges of two outlying provinces—that which lies between the southwestern boundary of Nevada and the Sierra Nevada and that which lies near the Colorado river and separates the Colorado plateau from the Basin region.

In the region where the relief is due primarily to erosion there are undoubtedly topographic features caused by direct deformation, which in this case is comparatively recent and is of much less importance than the older rock movements which erosion has overcome.

Faulting in general seems to be about as frequent as in other regions which show a similar amount of folding. The chief faults belong to a north-and-south and an east-and-west system. There are also diagonal ones running northeast and northwest, and in each of these systems they may have a very great displacement. In mining districts like Hamilton, Pioche, and Eureka there are many intersecting faults. This local complexity is connected with vulcanism and ore deposition, and the districts are the equivalents of Leadville and Aspen, in the Rocky mountains. Even here the faults generally have no primary effect upon the topography, as has been shown in the case of Eureka and Pioche, while at Hamilton simple fault-scarps, due directly to displacement, are probably present. This difference in the influence of faults on the topography, which is chiefly dependent upon their relative age, is similar to that in the Aspen district, where there is a complex of faults that developed slowly and at different periods, so that only the most recent have displaced the present surface.† In Meadow Valley canyon, south from Pioche, a few of the post-Pliocene faults are accompanied by a corresponding surface displacement, but generally erosion has erased their

* Dutton: Op. cit., pp. 118, 124, 125, 134.
See also J. E. Spurr: Succession and Relation of Lavas in Great Basin Region. Jour. Geol., vol. viii, no. 7, p. 636.

† Monograph xxx, U. S. Geol. Survey.

effects. The faults of the Colorado plateau, which have usually formed simple fault-scarps, belong to a recent epoch, and are contemporaneous with recent faults in the Great Basin region. The two provinces, however, differ very widely as to the relation of topography to deformation in each: first, because in the Basin region the influence of ancient deformation and erosion in mountain-making has been immense, while in the plateau this factor hardly exists, and, second, because the recent faults, which form the striking and almost solitary structural feature in the plateau, are, so far as yet studied, far less abundant and powerful in the Great basin.

History of Deformation in the Great Basin Province

*LATE CAMBRIAN MOVEMENT**

In many localities of extreme eastern Nevada and adjacent Oregon and Utah where examination has been made a striking difference in the geologic section, as compared with that farther west, has been observed. This difference lies in the absence or slight representation of the Silurian and Devonian. The upper horizons of the Cambrian and the lower ones of the Carboniferous are also often missing, so that the Coal Measures may rest on the Lower Cambrian.†

The general lack or scantiness of deposits representing such important periods, joined to the irregularity in neighboring districts as to the amount of missing strata, indicate that during a large part of the Devonian and Silurian this was an area of non-deposition, and that in this same period the Cambrian, and perhaps the Archean,‡ was deeply eroded.

This region is limited in Nevada (except in the northeastern part) by the meridian 114 degrees 30 minutes, west of which are many thousand feet of Silurian and Devonian,§ so the western district was at the bottom of a deep ocean at the period when the region farther east was a land mass. The limits of the continent whose existence is thus demonstrated are not yet known, but it was probably of considerable size. The uplift

*At present the obscurity of the record is such that it is hardly profitable to discuss disturbances of earlier date than this.

†S. F. Emmons: Geological Explorations of the Fortieth Parallel, vol. ii, p. 368, 444; Economic Geology of the Mercur Mining District, Utah, Sixteenth Ann. Rept. U. S. Geol. Survey, part ii, p. 360 (map and cross-section).

C. D. Walcott: Bull. 30, U. S. Geol. Survey, p. 38.

E. E. Howell: U. S. Geol. Surveys West of the Hundredth Meridian, vol. iii, pp. 238, 242.

G. W. Tower and G. O. Smith: Nineteenth Ann. Rept. U. S. Geol. Survey, part iii, p. 628.

C. E. Dutton: Monograph ii, U. S. Geol. Survey Atlas, sheets ii, xi, xiii, xiv, xxii.

C. D. Walcott: Am. Jour. Sci., vol. xxvi, p. 437.

‡Arnold Hague: Geological Explorations of the Fortieth Parallel, vol. ii, p. 421.

Clarence King: Same work, vol. i, p. 139.

§Arnold Hague: Monograph xx, U. S. Geol. Survey, p. 13.

which created it was probably in late Cambrian or post-Cambrian times, although it may have been later. That it was differential and was locally accompanied by folding and faulting is probable, but certainly the disturbance was not extensive, since within this ancient continental area the Carboniferous and Cambrian rocks seem nearly everywhere conformable.

POST-DEVONIAN MOVEMENT

Somewhere near the close of the Devonian or the beginning of the Carboniferous there was a general depression of the Silurian-Devonian continent below the level of the ocean, as is shown by the fact that there were deposited on it the same thick Carboniferous sediments as in the region farther west. This depression may have been accompanied by folding in some places, but so far there is no evidence of it, and from the general conformability of the Cambrian and Carboniferous, where these occur nearly or actually in juxtaposition, it is probable there was no widespread deformation.

POST-CARBONIFEROUS MOVEMENT

Mr King has reasoned * that after the Carboniferous period the region between the Wasatch and longitude 117 degrees 30 minutes in Nevada was elevated to a land-mass, so that it did not receive any Mesozoic sediments. What were the effects of this movement in mountain-building is uncertain, since they have been obscured to such an extent by the post-Jurassic upheaval.

POST-JURASSIC MOVEMENT

The Sierra Nevada, as proved by Whitney, experienced its chief folding and upheaval at the close of the Jurassic.† The range consists of a great series of slates and schists, which as a rule dip easterly. The apparent monocline which this dip indicates has been explained ‡ as a series of closely appressed and overthrown folds, the tops of which have been truncated. In this connection it is interesting to note that in the White Mountain range, which lies next east of the Sierras, Mr Walcott § has described an overthrown fold whose strata, however, dip westerly.

In the western part of the Great Basin the Jurassic and Triassic rocks are highly folded, suggesting that they took part in the post-Jurassic

* Geological Explorations of the Fortieth Parallel, vol. i, p. 759.

† H. W. Turner: Rocks of the Sierra Nevada, Fourteenth Ann. Rept. U. S. Geol. Survey, part ii, p. 441.

‡ Le Conte: Am. Jour. Sci., 3d ser., vol. xxi, p. 101.

J. S. Diller: Fourteenth Ann. Rept. U. S. Geol. Survey, part ii, p. 444.

§ Am. Jour. Sci., vol. xl, p. 169.

movement. Therefore Mr King* considered that the great ranges of western Nevada were thrown up at the same time as the Sierra. Whether this disturbance was felt as far east as the Wasatch Mr King was unable to tell, but he concluded that it was confined to the post-Carboniferous continent, which extended from the Wasatch westward to longitude 117 degrees 30 minutes, and west of the continent through a strip 200 miles wide, which included the present Sierra Nevada. The westernmost field of the upheaval was, therefore, that of the most powerful compression. Whether the disturbance was actually felt as far east as the Wasatch Mr King could not decide.

The approximate coincidence of the eastern limit of Jurassic folding with the eastern boundary of the post-Carboniferous continent appears, when considered by itself, very likely accidental. But the eastern boundary of the post-Carboniferous (Mesozoic) continent, in Utah and Nevada, seems to have coincided very nearly with the western boundary of the Silurian-Devonian continent.† Moreover, in southeastern Nevada, near the Utah boundary, the folded Basin ranges with their upturned Tertiaries are separated from the comparatively undisturbed Colorado plateau by approximately the same line, which was thus also the eastern limit of the more important Tertiary disturbances. Since early Paleozoic times, therefore, this north-and-south line has been a critical one in determining regions of deformation and sedimentation.

POST-CRETACEOUS MOVEMENT

At the close of the Cretaceous, according to King,‡ the stress which reelevated and folded the Rocky mountains produced its maximum disturbance near the western edge of the area it involved, in the region of the Wasatch, which was also near the western limit of Cretaceous sediments. That it was also felt farther west in the eastern part of the Great basin, which had been part of the post-Carboniferous (Mesozoic) landmass, is rendered probable by the fact that during the succeeding early Tertiary period this region suffered rapid and intense erosion, producing part of the thick early Eocene sediments of Utah and eastern Colorado.§

In the western part of the Great basin the absence of Cretaceous rocks prevents us from ascertaining whether this movement was felt. In the Sierra Nevada|| the Upper Cretaceous and Tertiary strata usually lie nearly or quite horizontal; west of the Sacramento valley, however, they are generally deformed.

* Geological Explorations of the Fortieth Parallel, vol. i, p. 747.
† See p. 242.
‡ King: Op. cit., p. 754.
Dana: Manual of Geology, 4th edition, pp. 359–364, 874.
§ King: Ibid; also op. cit., analytical map no. 4.
|| H. W. Turner: Seventeenth Ann. Rept. U. S. Geol. Survey, part i, p. 530.

In the Colorado Plateau region Dutton* finds that from the Carboniferous to the Cretaceous there was physical rest, but at the close of the Cretaceous, simultaneously with the Wasatch uplift, there occurred, on a comparatively slight scale, uplifting, flexing, and dislocating, followed by erosion.

EOCENE MOVEMENTS

The Eocene was a time of considerable disturbance in the Great basin. In the early part of the period the Vermilion Creek sediments were laid down in the Ute lake, with their westernmost and thickest portion near the Wasatch. The deposition of these beds was stopped by a period of folding along the western shore, during which the country west of the Wasatch sunk so that the Eocene waters ran 200 miles westward into Nevada, forming part of the Gosiute lake, in which was deposited the Green River Middle Eocene.†

After the Middle Eocene sediments had accumulated they were upheaved and bent into folds having as much as 40 or 50 degrees dip. This disturbance may have extended farther west, into the region of no known Eocene deposition, but there is no means of judging.

The belt of Triassic and Jurassic marine sedimentation in western Nevada and adjacent California, defined, according to King, by the elevation of eastern Nevada at the close of the Carboniferous, became shut off on the west and transformed into an elevated trough by the uplift of the Sierra Nevada at the end of the Jurassic. This depression was apparently above the sea during the Cretaceous and early Eocene, for no deposits of these periods have been discovered in it. But during late Eocene there were laid down in it extensive lake beds, which are found at intervals from the Silver Peak range southeastward into the Mojave desert, and these were followed by later Tertiary strata, so far little studied. Thus the present rather scanty evidence points to the close of the Middle Eocene as the time when the post-Jurassic depression was remodeled into a lake basin. The differential subsidence which effected this was therefore contemporaneous with the movement which according to King closed the existence of Gosiute lake. The general trough apparently extended at this period southeastward into the Mojave desert and Mexico, where the lake beds are replaced by Upper Eocene marine sediments, overlain by marine Miocene. The depression thus formed has persisted through Tertiary and Pleistocene time to the present day. It is now represented in Mexico by the gulf of California, and in California and Nevada by the Colorado and Mojave deserts and that relatively sunken westernmost belt of the Great basin which borders the Sierra Nevada.

*Second Ann. Rept. U. S. Geol. Survey, p. 65.

† King: Op. cit., pp, 747 and 755.

On the west the Sierra Nevada interposed between the Eocene lake and the ocean a barrier, which, judging from the thickness of the lake sediments, must have been high. If the east front of this range was determined by faulting, the displacement must have originated before this period. That the Tertiary movements which the Great basin underwent did not in general affect the Sierra Nevada, however, is shown by the circumstance that in this range the Tertiary strata lie nearly horizontal.

In the Colorado plateau Dutton * concludes that the region which had been submerged during the Eocene was uplifted at its close and exposed to denudation.

MIOCENE MOVEMENTS

King concluded that the entire western portion of the Great basin sank at the close of the Eocene, forming Pah Ute lake, which covered much of Nevada, Idaho, eastern Oregon, and part of California. Since the Sierra Nevada was the lake's western boundary, he reasoned that the eastern front of the range, which he believed a fault-scarp, originated when the basin was formed. But it has just been shown that this depression was made during the Eocene, and the movement permitting Miocene sediments to extend, as King has described, may have been a deepening of the earlier trough. The new sediments, so far as studied, seem to have been laid down on the older beds without any striking unconformity.

After the Miocene closed, its sediments were upturned in folds attaining a dip of as much as 25 degrees, and a new depression was formed, which received the Pliocene Shoshone lake.†

In the Sierra Nevada there was little or no folding. The lofty range which resulted from general uplift at the close of the Shasta-Chico Cretaceous ‡ had been actively eroded since then, and reached its stage of least topographic relief in the Miocene. Late in the Tertiary, according to Mr Diller,§ the elevation of the range was intensified by faulting. Nevertheless this was a region of little disturbance as compared with the Great basin.

In the Colorado plateau the Miocene was a period of slight deformation, resulting in gentle swells of the strata.||

PLIOCENE

The Pliocene Shoshone Lake deposits in the Great basin are usually

* Second Ann. Reprt U. S. Geol. Survey, p. 65.
† King: Op. cit., p. 456.
‡ J. S. Diller: Fourteenth Ann. Rept., part ii, p. 421.
§ Op. cit., p. 433.
|| C. E. Dutton: Second Ann. Rept. U. S. Geol. Survey, p. 65.

horizontal, showing that this period was not one of very great disturbance. Nevertheless there was probably some local folding and considerable uplift and subsidence on a large scale. Some of the folds and faults which had been previously formed continued their growth.

In the Death Valley region the earlier Tertiary plications became more marked, as shown by the upturning of probable Pliocene strata. At Twin springs, in the Pancake range, and in the Meadow Valley canyon the writer noted in Pliocene strata faults which are not so recent as those presently to be described as Pleistocene, since they are not expressed in the topography. It is possible that some of the larger folds, such as the anticlinal of the Mormon range, originated in the Pliocene. In Utah, Nevada, and the Great Plains region King has described an important broad tilting of the Pliocene strata.*

According to Mr Diller, the Sierra Nevada experienced at the close of the Pliocene a great elevation, accompanied by great volcanic activity.† This was followed by the erosion which wrought the present grand scenery of this range.

In the Colorado plateau the Grand canyon began to be cut, in consequence of the general deformation.‡

PLEISTOCENE

During the Pleistocene period local deformation has been comparatively active. Mr Gilbert has described and admirably discussed the many recent fault-scarps with vertical displacements of 100 feet and less which have been formed since the lake Bonneville epoch.§ Farther west, in the lake Lahontan basin, Professor Russell has discovered similar recent fault-scarps of about the same magnitude.|| In Meadow Valley canyon the present writer has observed post-Pliocene flexures and faults, some of which are so recent as to be directly expressed in the topography.¶ In the Funeral Range region the folding, which became active during the Tertiary, continued until it involved the probably Pleistocene basalts.

Besides absolute folding and faulting, there has been much warping, as is shown in the region north of lake Mono, where the sediments of the Pliocene Shoshone lake have probably been elevated 1,000 or 1,200 feet above their normal height, in conjunction with Pleistocene volcanic activity. This deformation is of the same important kind as that which Mr Gilbert recognized in Utah, where the Bonneville shorelines have ex-

* Explorations of the Fortieth Parallel, vol. i, p. 757.
† Eighth Ann. Rept. U. S. Geol. Survey, part i, p. 432.
‡ C. E. Dutton : Second Ann. Rept. U. S. Geol. Survey, p. 120.
§ Monograph i, U. S. Geol. Survey, pp. 340, 352, 354, 356, 361, 365, 367, 368, 371, 372.
|| Monograph xi, U. S. Geol. Survey, pp. 25, 27, 29, 274-283.
¶ See figure 1, plate 24.

perienced a differential epeirogenic movement, measuring as much as 350 feet vertically.

On the hypothetical old fault-faces on the western side of the Wasatch and the eastern one of the Sierra Mr King* thought to have found evidence of renewed post-Pliocene movements of 1,000 and 2,000 feet respectively. Mr Diller has described several Pleistocene faults in the Sierra Nevada, especially along the eastern front, near Honey lake, where the vertical displacement was about 3,000 feet.†

In 1872 a violent earthquake in Owens valley, California, signalized a movement which resulted, along the eastern foot of the Sierra, in fault-scarps with a maximum height of 20 feet.‡

In the Colorado plateau are a number of heavy north-and-south faults,§ whose extreme youth is shown by their displacing the probably Pleistocene basalts and by their having remained unaltered to any great extent by erosion.

CONCLUSION

While uplift and subsidence, involving the making of continents, and possibly of mountain ranges, went on in Paleozoic times, the earliest post-Archean mountain-making folding of which we have reliable record occurred in the Great basin at the close of the Jurassic, when many of the Great Basin ranges were probably formed, contemporaneously with the Sierra Nevada. Subsequently, mountain-making movements took place in at least part of the Great basin at the close of the Cretaceous and at several epochs during the Tertiary. In fact we may believe that folding and faulting has gone on steadily, though spasmodically, from the close of the Mesozoic until the present day, affecting the whole of the Great basin and extending from its borders to the country south and east. The Colorado plateau has been influenced most by the most recent of these movements. Major Powell's ‖ diagrams of the faults in this region show that the monoclinal fold is typically the precursor of the fault, as is so frequently the case elsewhere. Since the fold is manifestly due to compression, the fault must be also. This is in opposition to the views of Professor Russell,¶ who reasoned that a highly faulted district, such as he conceived the Great basin to be, has experienced extension and not compression.

In general the period of deformation which lasted from the Mesozoic

* Explorations of the Fortieth Parallel, vol. i, p. 758.

† Eighth Ann. Rept. U. S. Geol. Survey, part i, pp. 429, 432; Fourteenth Ann. Rept. U. S. Geol. Survey, part ii, p. 432.

‡ G. K. Gilbert: Monograph i, U. S. Geol. Survey, p. 361.

§ C. E. Dutton: Second Ann. Rept. U. S. Geol. Survey, p. 118; also Monograph ii, p. 117.

‖ Explorations of the Colorado River, Washington, 1875, pp. 183, 184, 190, 191, etc.

¶ Fourth Ann. Rept. U. S. Geol. Survey, p. 453.

to the present has been contemporaneous with volcanic activity. By far the most energetic vulcanism, so far as we know, occurred in the Tertiary, beginning probably in late Cretaceous or early Eocene and extending into the Pleistocene. Vulcanism and deformation were, therefore, allied phenomena.

Record of post-Mesozoic Erosion in the Great Basin

CRETACEOUS EROSION

The Great Basin region was probably above water during the Cretaceous, since no deposits of this period have been discovered. There must also have been long continued and deep erosion, which is evidenced by the great quantity of sediments derived from the Nevada land-mass and accumulated in the seas of Utah, Arizona, and California. During this vast period the Jurassic folds were probably dissected so that mountains of erosion originated. In the Grapevine mountains* we find evidence of a pre-Tertiary rugged range, whose rocks were very little folded. The same is true in the Mormon range, where there are ancient rhyolites and tuffs (Eocene?), whose beds abut laterally against Paleozoic limestone having the same attitude. This limestone formed horizontally stratified cliffs, against which the lavas and associated sediments were laid down, and both series have been involved in comparatively recent folding. The conditions demonstrated by these occurrences were very likely universal over the Great Basin region, so that there were developed numerous ranges, which had in general north-and-south trends, following the lines of post-Jurassic folding. During this period the climate was probably comparatively moist, and a large part of the Great basin was probably occupied by active rivers, which deepened them rapidly. Judging from the present height of the old core of the Grapevine mountains above the Tertiaries at their base, the ranges seem to have been far more rugged and picturesque and the valleys far deeper and narrower than now.

TERTIARY-PLEISTOCENE EROSION

Climatic control.—But directly at the close of the Cretaceous a time came when erosion was not sufficiently rapid to overcome crustal deformation Thus broad basins were formed, which were occupied by Eocene, Miocene, Pliocene, and Pleistocene lakes.†

* See p. 239.
† See footnote, p. 232.

Was it unusual rapidity of warping or abnormal inactivity of erosion which brought about the reversal of their ordinary relation? Other regions with more legible records aid in deciding. The great faults of the Colorado plateau seem to be among the most striking examples of rapid recent deformation. Some have displaced Pleistocene volcanic cones, and their courses are marked at the surface by scarps which are barely defaced by general erosion, yet the Colorado river and its tributaries cross them without any alteration of grade, showing that downcutting has easily kept ahead of differential uplift. No lake would be able to accumulate in the region traversed by these streams unless warping were much more rapid than the faulting has been.

Viewing examples like this, it seems improbable that the broad Tertiary lake basins under consideration could have long remained undrained had there been even moderately abundant precipitation. Indeed, part of the deposits of the Upper Eocene lake in southeastern California are of such a character as to indicate that a great inland sea underwent extensive evaporation, resulting in chemical precipitation from its waters. Therefore the general period of aridity had already begun at this time.

It is certain, however, that there were important fluctuations. In the same upper Eocene lake series that contain borax, gypsum, and calcareous tufa are beds with coal, fossil leaves, and silicified forests, testifying to moist intervals between the arid epochs. From the little we know of the Great Basin Miocene, it is probable that the same alterations of moist and dry climate took place. Most of the Pliocene must have been extremely dry, for the great Shoshone lake, marking a period of increased precipitation, apparently did not originate till near the close of the period, if we judge from its fossils, its relation to Pleistocene lakes, and the comparative freshness of its topographic work; and among these very lake-beds are some which are impregnated with alkaline carbonates, as if they had been deposited in saline waters.* Major Dutton † considered that the Pliocene in the Grand Canyon region was a time of aridity.

Within the Pleistocene the oscillations of climate are well known. King found in the deposits of lake Lahontan evidence of four alternating episodes of moisture and aridity, beginning with a moist period and ending with the present dry one. Subsequently Professor Russell ‡ prefixed to this series the dry pre-Lahontan episode, making five alternations. The succession is the same as that discerned by Mr Gilbert § in the history of lake Bonneville.

* King: Explorations of the Fortieth Parallel, vol. i, p. 439.
† Second Ann. Rept. U. S. Geol. Survey, p. 120.
‡ Monograph xi, U. S. Geol. Survey, p. 261.
§ Monograph i, U. S. Geol. Survey, p. 316.

Evidence of climatic variation in very recent times has been observed by Mr King in the Sierra Nevada.* About 1860 an increase of precipitation began, marked by forcing of the timber line downward by encroaching snow and by a rise in lake Mono. In Great Salt lake considerable historic oscillation has been chronicled.†

General leveling tendency.—During the Tertiary, as a whole, materials washed from the Great Basin ranges largely found their way into lakes or dry basins of the same region, so that erosion contributed to level the rugged topography instead of further differentiating it. The repeated Tertiary uplifts and foldings antagonized this tendency, sometimes uplifting portions of the detrital deposits so that they lay on the flanks of the ranges; but with little or no drainage to exterior regions these movements could result in no permanent commensurate effect onthe topography. During all the disturbances and after their close materials were steadily stripped off from the ranges and deposited in the valleys.

Active erosion in moister climatic intervals.—Quite as important as deformation, as an offset to the degrading and leveling tendency, has been the drainage instituted in the alternating intervals of moister climate. That during the Eocene there were periods of active erosion is shown by the enormous bulk of sediments derived from the Central Nevada land-mass which were laid down near the Wasatch and in southeastern California and adjacent Nevada. The same conclusion applies in a less degree to the Miocene and in a still less degree to the Pliocene Shoshone Lake epoch.

Erosion in drainage basins of Pleistocene lakes.—The lakes of the Pleistocene were probably of less extent than those of the earlier periods; they seem to have formed a relatively insignificant quantity of deposits, and so their feeding streams are to be credited with correspondingly little erosion. Yet Professor Russell measured a thickness of 375 feet of lake Lahontan sediments, while Mr Gilbert found 150 feet of Bonneville beds. In neither case was the bottom of the section reached, and the total amount is probably very greatly in excess of these figures. Estimating on the basis of 375 feet as the average thickness of sediment in each lake, the total bulk is 589 cubic miles for lake Lahontan and 1,312 cubic miles for lake Bonneville. When we consider the relatively small drainage basins of the lakes ‡ and remember that the material, which is rather uniformly spread out on deposition, has been derived chiefly from more restricted areas along the drainage lines, we perceive that even the rela-

* Explorations of the Fortieth Parallel Survey, vol. i, p. 527.
† G. K. Gilbert: Monograph i, U. S. Geol. Survey, p. 230, etc.
‡ Monograph xi, U. S. Geol. Survey, map, p. 30.

tively small amount of erosion indicated was capable of excavating deep canyons and of giving new relief to the mountains.

EROSION OF SOUTHEASTERN NEVADA DRY VALLEYS

Description of valleys.—The Bonneville and Lahontan Lake basins occupied only a fraction of the province which has hitherto been called the Great basin. But the limits of this region as an orographic depression of necessarily interior drainage will have to be considerably constricted on closer study, until they will very likely include little more than the Bonneville and Lahontan basins, together with the broad sunken belt lying east of and parallel to the Sierra Nevada and extending from the Lahontan basin nearly to the Mojave desert. A large part of southern Nevada has well defined valleys forming a part of the Colorado River system, which a week of rain would supply with streams. Meadow valley, which heads near the Pioche, is tributary to the Virgin river, an affluent of the Colorado. For the greater part of the course it is a magnificent canyon, cut sharply in Tertiary lavas and tuffs to a depth which in places reaches 2,000 feet. Down it small quantities of spring water run, partly under, partly over, the gravels, and very likely some finds its way to the Colorado. The canyon is continuous farther north with a typical flat desert valley called Duck valley, which extends beyond the 39th parallel. On the south Meadow valley is confluent, not far from its end, with the valley of Muddy creek, in which flow waters derived from a spring. Above the source of the spring a drainage channel extends northward nearly to the latitude of Eureka. Along this a little water flows, sometimes above and sometimes below the surface gravels, as in Meadow valley. In its upper portions it goes by the name of White river, and it is believed by the inhabitants that the White River water finds its way to the Colorado.

Farther southwest is the Las Vegas valley, which is even more plainly tributary to the Colorado than the other two, although it carries no running water. It is transverse to the strike of the stratified rocks, and separates the Spring mountain and Las Vegas ranges.

Age and origin of valleys.—These three valleys, with their branches, constitute a drainage system embracing nearly the whole of southeastern Nevada. That they are valleys of erosion is almost beyond question. This entails as a corollary the former presence of streams capable of carving them, and from this corollary the existence of a bygone episode of moister climate is deduced.

The valleys possess three relations which furnish clues to their age. The first is their membership in the Colorado River drainage system; the second is their relation to deposits of various periods, and the third

is their relation to the present as illustrated by the freshness of the river-cut topography.

According to Major Dutton* the Colorado drainage sytem was inaugurated in much its present form at the close of the Eocene, when the lakes of that period were drained. During the Miocene erosion went on rapidly, so that the streams cut down through Tertiary and Mesozoic strata till they reached the Carboniferous. At a period conjecturally placed at the beginning of the Pliocene the plateau region was uplifted and an arid climate succeeded to the preceding moister one. Many of the lateral streams dried up, and the cutting of the outer and broader gorge of the Grand canyon began. Soon after the uplift the rivers reached their baselevel and occupied themselves in widening their valleys. This epoch was closed by a new upheaval; assumed to have been near the close of the Pliocene. Consequent and subsequent was the cutting of the inner gorge of the Grand canyon. During this process came a time of moister climate, intervening between the two arid periods of the Pliocene and the present. This Dutton believed to represent the Glacial period. During this relatively short epoch new ravines were begun, while some of the older canyons were probably deepened. Most of these comparatively recent minor gorges are now dry and are being rapidly filled with alluvium. "The recurrence of a climate sufficiently moist to sustain a vigorous perennial stream would probably sweep out all this unconsolidated alluvium and return the valley to its former condition of an ordinary canyon."†

The features of the dry valleys of southeastern Nevada are not all equally ancient. Las Vegas valley is upward of 10 miles broad in its middle portion. It is cut in Paleozoic limestones and is floored with thick subaerial wash, which doubtless hides Tertiary beds. Sierra valley, through which White river runs, and Pahranagat valley, in which lies another portion of the drainage channel between White river and Muddy creek, are of the same type as Las Vegas valley, though narrower. But Meadow canyon is cut in the bottom of an older valley, which is like that just mentioned, and it has exposed the Tertiaries which are hidden in the others.

Comparing these features with the general topographic stages adduced by Major Dutton, we find that the older wide valleys have not participated in the active erosion which produced the inner gorge of the Grand canyon, but judging from their considerable depth and from their being cut in Paleozoic rocks they may have been somewhat eroded during the excavation of the outer gorge. They probably originated as early as did

* Monograph ii, U. S. Geol. Survey, p. 219 et seq.
† Op. cit., p. 229.

the Colorado Plateau drainage system. The Meadow Valley canyon, however, is of the same type and age as the inner gorge, and in that it shows evidence of having been cut during a short and relatively recent humid period, succeeded by the present period of aridity, it belongs to the class of gorges which Major Dutton believed to have been formed during that Pleistocene moist epoch which he correlated with the Glacial period.

Considering the relation of the dry southeastern Nevada valleys to the associated deposits, we note that Meadow Valley canyon cuts nearly horizontal lake sediments, which, on account of their relation to the general crustal deformation, have been provisionally classed as very late Pliocene. It also cuts a series of volcanics, the youngest of which is believed, from a comparative study of Great Basin vulcanism,* to be very late Pliocene or very early Pleistocene. When the canyon was nearly completed scant basalts and rhyolites were poured out, which, by the above method, are classed as Pleistocene. But the late Pliocene sediments and lavas were deposited in the bottom of the older valleys.

Considering the relation of the canyon to the present time, as illustrated by the freshness of the topography, we observe that the gorge is not encumbered with Pleistocene alluvium like that which has accumulated in the wider valleys. Where the canyon widens to a basin near Panaca, the terraces suggest a lake which was drained by the down-cutting. These features point to a comparatively recent portion of the Pleistocene as the epoch of canyon erosion.

The assembled deductions from these three relations lead to the conclusion that Meadow Valley canyon originated in an intermediate epoch of the Pleistocene, which was a period of humidity as compared with the preceding and succeeding ones. The wider detritus-floored valleys tributary to the Colorado experienced no erosion during the greater part of the Pleistocene, but were, perhaps, deepened and widened during the earlier Pliocene. Their origin as erosion features probably dates back as far as the Eocene.

We may test these conclusions by comparison with related phenomena in other parts of the Great basin. The ancient lakes, Lahontan and Bonneville, originated in a moist interval of the Pleistocene, preceded and succeeded by arid epochs. This interval was believed by Gilbert, Russell, and others to have been contemporaneous with the Glacial period. During their existence limited quantities of basalt were extruded. The topographic records left by these water bodies are com-

* J. E. Spurr: Journal of Geology, vol viii, no. 7, pp. 630, 637, 642.

paratively fresh. The closeness of the comparison indicates that Meadow Valley canyon was cut during the Bonneville and Lahontan epoch.

In an unpublished study the writer has concluded that the Pliocene lake Shoshone came to an end in the late Pliocene or early Pleistocene through the destruction of its basin by the relative depression of southern Nevada and California. He suggested that this southerly tilting was the same as that which produced the acceleration of the Colorado and the consequent beginning of the inner gorge of the Grand canyon described by Major Dutton as occurring at the close of the Pliocene. In western Nevada the disappearance of the Shoshone depression was closely followed by the formation of the smaller basin in which, after a period of dryness, lake Lahontan formed.

NET RESULT OF LEVELING AND DIFFERENTIATION TENDENCIES

But in spite of the attempts instituted during the intervals of moister climate the net result of the contending processes has been to fill the valleys at nearly the same pace as the lowering of the mountains. Materials removed by erosion go at once toward smoothing out topographic irregularities. The process is the reverse of that by which the mountains were originally differentiated, and if it continues at the rate it has maintained since late Tertiary it will end by reducing the region to a great waste without mountains or valleys and covered by drifting sands.

As yet, however, the work is only half finished. The crests of half-buried mountains stand out from intervening stretches of desert plain which occupy the position of the old valleys.

Thus the general topography, although striking, does not indicate extraordinary structure, but only exceptional conditions of erosion and deposition. Suppose the Appalachians, which likewise consist of parallel ridges eroded along lines of folding, should become arid, so that the rivers were unable to remove the detritus and the valleys become choked. There would develop in course of time exactly what exists in the Basin region, namely, a nearly level desert, containing a series of parallel, synclinal, and anticlinal ranges.

ARIDITY AS A PROMOTER OF STEEP SLOPES

The desert ranges generally terminate in the plains with a fairly moderate slope. Steep slopes or scarps are rather the exception, and when present they are not more abrupt than in the Rocky mountains or in the Alaskan ranges, though by rising from level deserts they often acquire a borrowed emphasis. Such scarps have been assumed to be directly due to faulting. It has been and will be repeatedly shown in this essay that

many of the most pronounced scarps are along no fault line, while many heavy faults have absolutely no direct effect on the topography. The theory appears, then, in general untenable. Indeed, the writer holds that in the erosion of rocks of unequal resistance scarps are natural and in many cases inevitable. Where not only the rocks but the distribution of eroding agents is unequal the inequality of the resultant topography is still greater. Thus in arid regions, where the general erosion is slight, whatever temporary or permanent lakes and streams exist undercut the bases of the otherwise comparatively stable mountains. Major Powell* speaks of the cliffs of the Colorado plateau as being "carried back for great distances by undermining, which is a process carried on only in an arid region." In the Great basin, mountain springs of comparatively insignificant volume have succeeded, by virtue of their monopoly of erosion, in eroding deep canyons with perpendicular walls, while the adjacent channels of occasional drainage are shallow valleys. In past times, especially during the Pliocene, great lakes have fretted the bases of the numerous mountain ranges which rose above their waters, so that the continual tendency has been to cut them back.

Relative Ascendency of Erosion and Deformation

The greater portion of the Basin ranges already described have been found independently in each case to be ranges of erosion. Deformation seems to have been slower than erosion, so that in the long run it has generally been outstripped. Yet it has often been more spasmodic, so that for limited periods it has held its own. Thus there are folds and faults which are directly expressed in the topography. These, however, are exceptional, as they are in most provinces, and excite special attention. One may find similar phenomena in other mountain regions, such as the Rockies.

Relative Ascendency of Folding and Erosion

The Synclinal Ridge of Erosion

The most common mountains are those which possess synclinal ridges; in these erosion has overbalanced deformation by folding (see plate 24, figure 5, and plate 25, figures 1 and 2).

The Anticlinal Ridge of Erosion

The next commonest class comprises anticlinal ridges which offer evi-

* Explorations of the Colorado River, pp. 69–72.
See also C. E. Dutton: Monograph ii, U. S. Geol. Survey, pp. 222, 227.

dence of having been determined by long continued erosion. The evidence may consist in close association with synclinal ridges of the same age or by the presence within the anticlinal ridges themselves of faults whose surface displacement has been effaced by erosion. The cores of the anticlines are generally of more resistant rock than the other strata, and have therefore persisted as ridges (see plate 24, figure 6).

THE MONOCLINAL RIDGE OF EROSION

Monoclinal ridges are usually minor and non-persistent features. They generally occupy a single limb of a fold. When a deep valley has been eroded along the axis of an anticlinal mountain and, together with the valleys on either side of the main range, has been partially filled with wash, it will then be transformed into a strip of desert dividing two monoclinal ridges, facing in opposite directions. Each limb of such a fold may be made up of thick strata, which erosion, working most powerfully along softer beds, may carve into a series of monoclinal ridges, all facing the same direction (see plate 24, figure 5).

THE ANTICLINAL RIDGE OF DEFORMATION

A fourth and unusual class comprises anticlinal mountains without cores of relatively greater resistance. These ranges generally consist partly or wholly of upturned Tertiary rocks; therefore their upheaval must have been comparatively recent. In some cases movement has probably continued into the Pleistocene. Such mountains seem to be the result of folding so rapid that erosion has been left behind. The aridity of the region has, of course, been favorable to this result (see plate 24, figure 4, and plate 25, figure 4).

Relative Ascendency of Faulting and Erosion

PRINCIPAL ASCERTAINED FAULTS OF GREAT BASIN

The faults in the Great basin belong to general systems. The two chief sets run north-and-south and east-and-west, while important sets are oblique, one trending northeast and another northwest. Following, on page 258, is a rough table showing localities of actually ascertained heavy faults.

The east-west faults seem as numerous as the north-south ones and their displacements equally great.

The fault systems are intimately related to corresponding systems of folds. Throughout most of Nevada the axes of folds trend north and south, but there has been much minor compression along east-west lines,

and in the southern part of the state these are locally dominant. Parallel with the Sierra is a belt of northeast striking major folds, and this is succeeded farther east by a zone of northeast axes, the two coming together in extreme southern Nevada (see plate 22). These fold and fault systems are probably to be interpreted as manifestations of a general long continued compression rather than of different forces acting separately and consecutively.

Table of Localities of Observed heavy Faults

North-south	*Oblique*		*East-west*
	Northeast-southwest.	*Northwest-southeast.*	
Humboldt range.			Humboldt range.
Piñon range.	Piñon range.		
West Humboldt range.		West Humboldt range.	
Schell Creek and Highland ranges.			Schell Creek and Highland ranges.
White Pine mining district.		White Pine mining district.	White Pine mining district.
		Eureka mining district.	
			Quinn Canyon range.
Pancake range.			
Hot Creek range.			Hot Creek range.
			Toyabe range.
Virgin range.		Snake range.	Snake range.
Hyko range.			Hyko range.
Pahranagat range.			Pahranagat range.
Timpahute range.			Timpahute range.
	Grapevine range.	Grapevine range.	
			Havallah range.
			Meadow Valley range.

GENERAL RELATIONS OF FAULTS TO TOPOGRAPHY

Where a fault or fold has deformed the surface, producing a scarp, an anticlinal ridge, or synclinal valley, the topographic form may be spoken of as *directly due to deformation;* but where a feature of relief has been carved out by atmospheric agencies (whatever may have been the governing influence of structure in determining lines of easiest erosion) it may be considered *directly due to erosion.*

Following are definitions of terms relative to the influence of faults on topography:

1. Where a fault has displaced the surface and the break remains undefaced or only slightly obscured we may call the resulting cliff a simple fault-scarp.

2. Where erosion has acted unequally along a fault on account of the difference as to hardness between two rocks forced into juxtaposition or between a crushed zone and an intact one the resultant cliff may be termed an erosion fault-scarp.

In the simple fault-scarp the cliff is always on the upthrown side of the fault. In the erosion fault-scarp it may be on the upthrown or down-thrown side, according to local conditions. In the former case it may be called a normal erosion fault-scarp; in the latter, a reversed erosion fault-scarp. It is generally difficult, without collateral evidence, to distinguish a simple fault scarp from a normal erosion fault scarp.

Since faults are closely related to folds as deformation features, their stages of relative ascendency over erosion are also analogous. The simple fault-scarp is analogous to the anticlinal ridge of deformation, the normal erosion fault-scarp to the anticlinal ridge of erosion, and the reversed erosion fault-scarp to the synclinal ridge of erosion.

Where the solid rock on both sides of a fault is equally resistant, but there is a zone of crushing, erosion produces a gully; where the movement has not materially weakened the rock the fault may have no effect whatever on the topography.

The accompanying sections of actual faults (see plate 23 and plate 24, figures 1, 2, and 3) illustrate their various relations to topography. They have been purposely taken from the Great basin, and, so far as possible, from other observers than the writer.

RELATION OF FAULTS TO GREAT BASIN TOPOGRAPHY

There is a general impression that the Great Basin mountain scarps are topographic features peculiar to the region. Judging from his own observations the writer believes this erroneous. These ranges have about the same amount of steep or perpendicular faces as other mountains—not so large as some and greater than others. Their most typical form of front has indeed a fairly moderate slope (see plate 21.)

Nevertheless there are frequent bolder faces or scarps which might be assumed to be due to faulting. Studying the field without prejudice, the writer could not long entertain this general idea of their origin, since he found no evidence positively corroborating it and much against it. The points of unfavorable evidence are briefly as follows:

(1) The faults actually observed in this region are comparatively few. Actually ascertained heavy faults along the main fronts of ranges are exceedingly rare.

(2) The transverse faults which run across the general trend of the Basin ranges are, so far as observed, equally or more numerous than the

north-south ones, and they display more openly their relations. In general they either have no effect on the topography or have induced the formation of gulches. Occasionally they are accompanied by cliffs, which are usually of trifling height as compared with the displacements. These can often be proved to be erosion fault-scarps, not unfrequently reversed. Finally there are rare faults, generally of relatively small displacement, which have a direct effect on the topography and have produced simple fault-scarps.

History of the Development of the Fault Theory as Applied to the Basin Ranges*

In the Colorado plateau there is a series of north-and-south displacements which have produced simple fault-scarps. The coincidence of the direction of these scarps with the trend of the ranges of the Basin region, which adjoins the plateau on the west and northwest, suggests to the observer acquainted with the plateau that the ranges are the result of more powerful faulting. Thus Mr G. K. Gilbert in 1873, after reconnaissance in the Basin region, concluded that the Basin ranges probably owed their definition and relief to faulting. He classified the sections accumulated by the geologists of the Wheeler survey as follows: †

1. "Faulted monoclinals occur in which the strata on one side of the fault have been lifted, while those on the opposite side either do not appear (*a*) or (less frequently) have been elevated a less amount (*b*). Two-thirds of the mountain ridges can be referred to this class."

2. "Other ridges are uplifts limited by parallel faults (*c*), and to these may be assigned a few instances of isolated synclinals (*d*), occurring under circumstances that preclude the idea that they are remnants omitted by denudation."

3. "True anticlinals (*e*) are very rare, except as local, subsidiary features, but many ranges are built of faulted and dislocated rock-masses (*f*) with an imperfect anticlinal arrangement."

"Not only is it impossible to formulate these features by the aid of any hypothetical denudation in such a system of undulations and foldings as the Messrs Rogers have so thoroughly demonstrated in Pennsylvania and Virginia, but the structure of the western Cordillera system stands in strong contrast to that of the Appalachians. In the latter corrugation has been produced commonly by folding, exceptionally by faulting; in the former commonly by faulting, exceptionally by flexure. In the latter few eruptive rocks occur; in the former volcanic phenomena abound, and are intimately associated with ridges of upheaval. The regular alternations of curved anticlinals and synclinals of the Appalachians demand the as-

* This outline has purposely been made compact, with minor features omitted.

† Progress Rept. Geog. and Geol. Survey West of the Hundredth Meridian, 1872, published in 1874, p. 50

sumption of great horizontal diminution of the space covered by the disturbed strata, and suggest lateral pressure as the immediate force concerned, while in the Cordilleras the displacement of comparatively rigid bodies of strata by vertical or nearly vertical faults involves little horizontal diminution and suggests the application of vertical pressure from below."

The earlier and more prolonged work of the geologists of the Fortieth Parallel survey had led them to conclusions different from Mr Gilbert's. Mr Clarence King, writing in 1870,* said:

"These low mountain chains which lie traced across the desert with a north-and-south trend are ordinarily the tops of folds whose deep synclinal valleys are filled with Tertiary and Quaternary detritus."

Major J. W. Powell, in 1876, accepted, with some reservation, the previously cited conclusions of Mr Gilbert. He described the structural characteristics of the Basin ranges as follows: †

"The Basin province is characterized by north-and-south ranges that are monoclinal ridges of upheaval, and these monoclinal ridges are separated by stretches of subaerial gravels that mask the structure of the areas of subsidence; but while this is the prevailing structure other types are found."

The general acceptance of the fault theory appears to have influenced Mr King's earlier conclusions, for in later writings, while maintaining his earlier statement that the Basin ranges are a series of folds, he granted the existence of abundant vertical faults and admitted the resultant dislocation into blocks, as claimed by Gilbert and Powell. He wrote, in 1878, as follows: ‡

"The frequency of these monoclinal blocks gives abundant warrant for the assertions of Powell and Gilbert that the region is one prominently characterized by vertical action; yet when we come to examine with greater detail the structure of the individual mountain ranges, it is seen that this vertical dislocation took place after the whole area was compressed into a great region of anticlinals with intermediate synclinals. In other words, it was a region of enormous and complicated folds, riven in later time by a vast series of vertical displacements, which have partly cleft the anticlinals down through their geological axes and partly cut the old folds diagonally or perpendicularly to their axes."

He concluded thus: §

"The geological province of the Great basin, therefore, is one which has suffered two different types of dynamic action: one, in which the chief factor evidently was tangential compression, which resulted in contraction and plication, presumably

* Geological Explorations of the Fortieth Parallel, vol. iii, 1870, p. 451.

† Geology of the Eastern Portion of the Uintah Mountains, p. 29.

‡ Explorations of the Fortieth Parallel, vol. i, p. 735.

§ Loc. cit., p. 744.

in post-Jurassic time; the other, of strictly vertical action, presumably within the Tertiary, in which there are few evidences or traces of tangential compression."

Major Dutton, in 1880,* followed closely the compromise views of King. He discussed the folding in the Great Basin ranges of Utah as follows:

"These flexures are not, so far as can be discerned, associated with the building of the existing mountains in such a manner as to justify the inference that the flexing and the rearing of the ranges are correlatively associated. On the contrary, the flexures are in the main older than the mountains, and the mountains were blocked out by faults from a platform which had been plicated long before, and after the inequalities due to such pre-existing flexures had been nearly obliterated by erosion. It may well be that this anterior curvation of the strata has been augmented and complicated by the later orographic movements. But it is not impossible to disentangle the distortions which antedate the uplifting from the bending and warping of the strata which accompanied it, and it is only the latter that we can properly associate and correlate with the structures of the present ranges. These present no analogy to what is usually understood by plication. The amount of bending caused by the uplifting of the ranges is just enough to give the range its general profile and seldom anything more."

It will be seen that Dutton's views favored more strongly the fault hypothesis than did King's. King believed that plication had been an important factor in creating the ranges, while Dutton supposed that the surface effects of folding were obliterated by erosion, which reduced the country to a comparatively level platform. Subsequently this plicated platform was broken by powerful faults, like those of the Colorado plateau, into a number of blocks, which were uplifted and tilted so as to form ranges. These ranges, according to this idea, are actually monoclinal blocks in origin, although not necessarily or even generally so in structure.

The explanations of Dutton were adopted almost exactly by Professor I. C. Russell. In 1884 he wrote as follows: †

"The whole of the Great basin thus far explored is remarkable for the persistency of a single type of mountain structure. This is the simplest of orographic forms, and has been already mentioned as a tilted block, bounded by faults. The whole immense region lying between the Sierra Nevada and Rocky Mountain systems has been broken by a multitude of fractures, having an approximately north-and-south trend that divides the region into long, narrow orographic blocks. These have been tilted so as to form small but extremely rugged mountain ranges, often from 50 to 100 miles in length, with a width of but a few miles. This region may be classed as a 'zone of diverse displacement' of vast dimensions.‡ If we draw

*Geology of the High Plateaus of Utah: U. S. Geog. and Geol. Surveys of the Rocky Mountain Region, p. 47.

†Fourth Ann. Rept. U. S. Geol. Survey, p. 443.

‡For types of displacements consult "Geology of the Uintah Mountains," Powell, pp. 16, 17.

across the map of the Great basin an east-and-west line touching the southern end of Great Salt lake, it will intersect not less than twenty lines of profound displacement. Farther south, in the latitude of Sevier lake, the number of orographic blocks into which the country has been broken is even greater.

"As already stated, that part of the Great basin lying north of the Nevada-Oregon boundary has the same pronounced orographic structure as the main area of interior drainage. In considering the physical history of the Great basin as a whole, however, we find over a wide area two distinct types of structure belonging to widely separated periods and due to forces acting in different directions. During the first period the rocks were plicated and crumpled into anticlinal and synclinal folds, and at the time of the second disturbance the present topography, due to orographic displacement, was initiated. These two periods of orographic movement were recognized by Mr King, who speaks of the Great basin as a 'region of enormous and complicated folds, riven in later times by a vast series of vertical displacements.' *

"These two types of structure are apparent at many localities throughout the central portion of the region of interior drainage, but immediately north of the Nevada-Oregon boundary, where the rocks are almost entirely volcanic, we find only such disturbances as are due to faulting. The age of the volcanic beds in the northern extremity of the Great basin would, therefore, seem to be intermediate between the two periods of disturbance."

In subsequent papers Mr Russell reiterated these conclusions. In 1886 Mr J. S. Diller extended the application of the fault hypothesis to the Sierra Nevada. He remarks: †

"Structurally the Sierra is like the Great Basin range, differing chiefly in the magnitude and in the present elevation of the blocks. Like the orographic blocks of the Great Basin area, they are composed of plicated strata, the folding of which, as has been pointed out by a number of observers, took place long before the faulting that gave birth to the peculiar features of the ranges. It is important to remember the fact that at the time the strata of which the Sierra Nevada range is composed were folded—*i. e.*, about the limits between the Jurassic and Cretaceous periods—the Sierra Nevada range was not differentiated from the continental mass of the Great Basin region, and it was not until a very much later period that this separation occurred."

In a paper published the succeeding year he wrote as follows: ‡

"The plication of the strata in the Sierra Nevada range took place, at least in great part, about the close of the Jurassic or beginning of the Cretaceous period, but the faulting which really gave birth to the Sierra as a separate and distinct range by differentiating it from the great platform stretching eastward into the Great Basin region did not take place until toward the close of the Tertiary or the beginning of the Quaternary.

"Although the faulting may have commenced earlier, the greater portion of the

* U. S. Geological Explorations of the Fortieth Parallel, vol. i, p. 735.

† Bull. U. S. Geol. Survey, no. 33, p. 15.

‡ Bull. Phil. Soc. Wash., 1887, vol. ix, p. 4.

displacement has taken place since the beginning of the great volcanic outbursts in the vicinity of Lassens peak. If we may accept numerous small earthquake shocks as evidence, the faulting still continues."

Besides the writers above mentioned, the theory of the direct origin of the Great Basin ranges by faulting has been accepted and elaborated by Professor Le Conte and others.

In opposition to this general acceptation Professor James D. Dana examined the question and found the data insufficient for the proof of the fault hypothesis. He wrote in 1895 as follows: *

"Gilbert, in view of the great displacements by nearly vertical and largely downthrow faults, designated the system of mountain-forming movements the 'Great Basin system.' He shows that the displacements are along the old fault planes and also along new planes of fracture made in the course of the Tertiary era and later.

"Great displacements along old and new fault planes have been shown to have taken place also in the high plateaus of Utah and in the Uintah mountains, others in the Wasatch, and still others in the Sierra Nevada, which are referred to the Great Basin system. The fact of such movements extending into recent time has been urged by Powell, Gilbert, Russell, Le Conte, Diller, and others.

"The *ridges* of the Great basin, made thus of upturned and plicated rocks, have been assumed to be each limited by faults and to have undergone up-and-down movements and variously tilting displacements, and thus to have become in effect 'monoclinal orographic blocks' in the 'Basin system,' each block making by itself a monoclinal mountain, even when not so in its bedding (Russell, 1885). In the ideal sections made to illustrate this hypothesis the wide intervals of alluvium (that is, of buried and concealed rock) are represented as underlaid each by a block at lower level or by the subterranean continuance of one sloping ridge to the next, and the actual flexures or lines of bedding have been omitted and monoclinal lines substituted. They are intended to exhibit the supposed structure; but until the stratigraphy of the ridges of the whole basin shall have been studied and sections of them represented and the relations of each ridge to those lying on the same northward and northwestward line of strike shall have been thoroughly investigated, general stratigraphic conclusions can not be safely drawn."

Analysis of the Fault Hypothesis

The present writer, seeking the foundation of facts on which rests the fault theory of the origin of the Basin ranges, has been obliged to fall back almost wholly on the original work of Mr Gilbert, who appears to have conceived the hypothesis. The views of subsequent investigators seem to have been based chiefly on the *à priori* assumption that all the scarps of the region were necessarily fault-scarps, and much of the literature has been prepared with little or no personal acquaintance with the field.

* Manual of Geology, 4th edition, p. 366.

Analyzing Mr Gilbert's reasons for the propounding of the hypothesis, moreover, we find them almost wholly physiographic. The frequently abrupt ascent of the mountains from the level desert and the proximity of the great fault-scarps of the Colorado plateau seem to have suggested the idea. They may be epitomized as follows:

(1) The ranges are principally monoclinal blocks. (2) These blocks are limited on one or both sides by scarps. (3) These blocks and scarps can not have been formed by erosion, and must therefore be fault-scarps.

On this foundation there rests a great superstructure of theory and deduction.

The refutation of these points may be summarized from the foregoing pages:

1. According to the accumulated record of observation, ranges consisting essentially of a single monoclinal ridge are exceedingly rare. The writer does not remember a single instance where such a structure was persistent when followed sufficiently far along the strike. The apparent monocline almost invariably merges into a synclinal or anticlinal fold, of which it constitutes one of the limbs.

2. The writer has undertaken to show that the mountain fronts studied are, in general, not marked by great faults, and, conversely, that the ascertainable faults are very rarely attended by simple fault-scarps.

3. In regard to the impossibility of erosion producing the desert ranges as we have them, especially the monoclinal ridges, the writer finds chiefly the most normal type of erosion in the Great basin. In this point, however, he is glad to call the opinion of Mr Clarence King to his aid, who has shown that in the Fortieth Parallel region the monoclinal ridges are in most cases parts of anticlinal or synclinal folds, and can be traced into them longitudinally.*

Summary

The conclusion is that the topographic forms of the Great basin, as we see them, are the net results of compound erosion active since Jurassic times, operating on rocks upheaved by compound earth movements which have been probably also continuous during the same period. Only the more recent faults or folds find direct expression in the topography; the older ones are mastered by erosion. In general, in this region, as in most others, deformation lags behind erosion. This is true chiefly of the local movements, which produce faulting and folding, and not of vast general upheavals and depressions, which seem relatively

*Geological Explorations of the Fortieth Parallel, vol. i, p. 737

rapid. But folding, and especially faulting, are of irregular speed, erosion is more uniform, so that local deformation may outstrip er for a time, but in any long period is likely to be beaten itself. Th the faults actually observed in the Great basin, among them even post-Pliocene faults, nearly all have no *direct* expression in the t raphy. Nevertheless, some Pleistocene faults are expressed in th pography, and these have sometimes a very great displacement, the Colorado plateau.

In the case of the Grapevine mountains the range appears to have already in existence in pre-Eocene or Cretaceous times. In some mountains of erosion which have not suffered comparatively recen formation, as has the range just mentioned, their ancient origin i more clear, for the Tertiary beds rest against their bases unconform generally occupying only the present valleys and not being found mountains. Therefore the main system of ranges was probably lai in pre-Tertiary times. It was at the close of the Jurassic, so far can judge from the rather scant evidence, that the Great Basin r was uplifted above the sea and plicated. During the Cretaceou region was probably a land-mass, and this was very likely the p when many of the ranges were differentiated. Their regularity more than one would expect in view of their resulting from pa folds, and is not so striking as in the Appalachian region. To ex this early dissection we must assume a greater precipitation than and must conclude that the country was traversed by many r Subsequently the climate became arid and the water supply wa sufficient to remove the detritus from the valleys, which filled t that for a long period the reverse of differentiation, or leveling, has going on. Nevertheless the Tertiary rocks show that warping, fol and faulting went on continuously all through the Tertiary int Pleistocene, and is even now progressing. To this warping, doub the Tertiary lake basins were due.

According to this conclusion these mountains are not simple in and structure. However, the writer would compare the typical range to the less compressed portions of the Appalachians and the Among the exceptional types of ranges the Funeral Range type is spicuous. This has a structure similar to that of a portion of the mountains, as described and figured by Professor Davis.*

* Physical Geography, 1899, p. 168.

TYPICAL FRONT OF GREAT BASIN RANGE

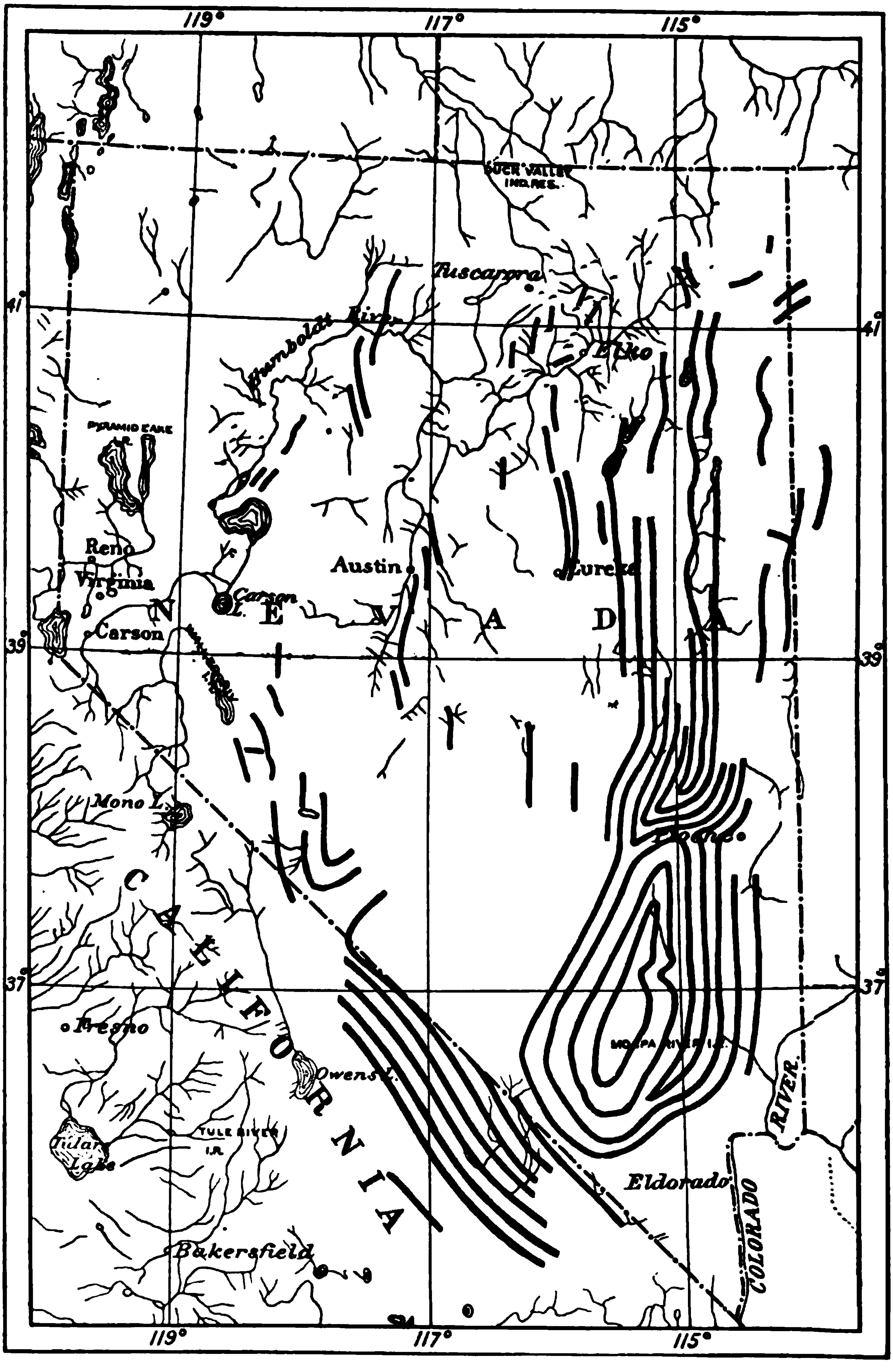


DIAGRAM OF OBSERVED FOLD AXES IN NEVADA AND ADJACENT CALIFORNIA

Explanation of Plates

Plate 20.—*Great Basin Ranges of Southern Nevada and adjacent California*

Plate 21.—*Typical Front of Great Basin Range*

East front of minor range west of the Egan range, near Ely

Plate 22.—*Diagram of observed Fold Axes in Nevada and adjacent California*

Each line follows approximately the axis of an anticlinal or synclinal fold. Strike lines which are not proved to be along fold axes have been omitted. Axes in northern portion of diagram are from King (Fortieth Parallel Report, volume I, analytical maps XI and XII). The rest are from observations by the writer.

PLATE 23.—*Effects of Faulting on Topography*

FIGURE 1.—Faulting at Eureka, Nevada (after Hague).

From Monograph XX, U. S. Geological Survey, Atlas Sheet XIII. Section G H. Shows ascendency of erosion over faulting. *a*, slight erosion fault-gully; *b*, slight normal erosion fault-scarp; *c*, slight reversed erosion fault-scarp. Scale, 1 inch = about 1,350 feet.

FIGURE 2.—Ideal result of ascendency of faulting over erosion (Spurr).

Ideal figure to show what would have been the approximate topography of figure 1 had faulting outstripped erosion. Scale, 1 inch = about 1,350 feet.

FIGURE 3.—Faulting at Eureka, Nevada (after Hague).

Also from Monograph XX, Atlas Sheet XIII. Section A B. Shows ascendency of erosion over faulting. Reversed erosion fault-scarp. Scale, 1 inch = 1,350 feet.

D = Nevada limestone (Devonian); W. P. = White Pine shales (Devonian); L. C. = Lower Coal Measures strata. The fault shown in the section is a normal fault, having the downthrow on the left as we look at the figure, yet the downthrown block forms a prominent scarp rising above the upthrown block and worn only a little back from the fault-plane. This is therefore a reversed erosion fault-scarp caused by the greater resistance of the Lower Coal Measures as compared with the softer White Pine shales.

FIGURE 4.—Faulting at Pioche, Nevada (after Howell).

From U. S. Geographical Surveys West of the One Hundredth Meridian, volume iii, Geology, page 259, figure 103. Shows ascendency of erosion over faulting. Reversed erosion fault-scarp.

A = Cambrian quartzite; C = Cambrian limestone of a higher horizon than the quartzite. The fault shown in the section is a normal fault. The block on the right of the figure being relatively downthrust, the scarp shown is a reversed erosion fault-scarp.

FIGURE 5.—Faulting at Pioche, Nevada (after Howell).

From the same page as figure 4. Shows ascendency of erosion over faulting. *a*, erosion fault-valley; *b*, fault with only slight effect on topography. In addition to the strata in figure 4, *b* here equals Cambrian shales intermediate in position between the limestone and the quartzite. The fault at *a* has determined a fault-gully, while the fault *b* has had very little influence on the topography.

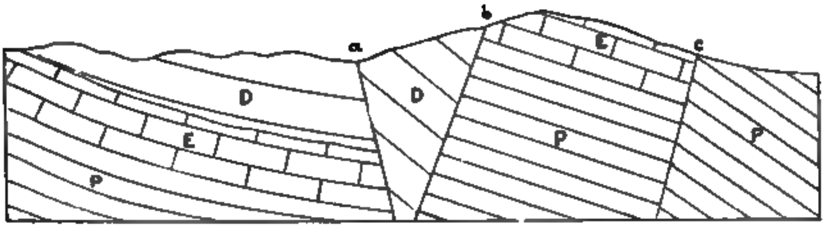


FIGURE 1.—FAULTING AT EUREKA, NEVADA

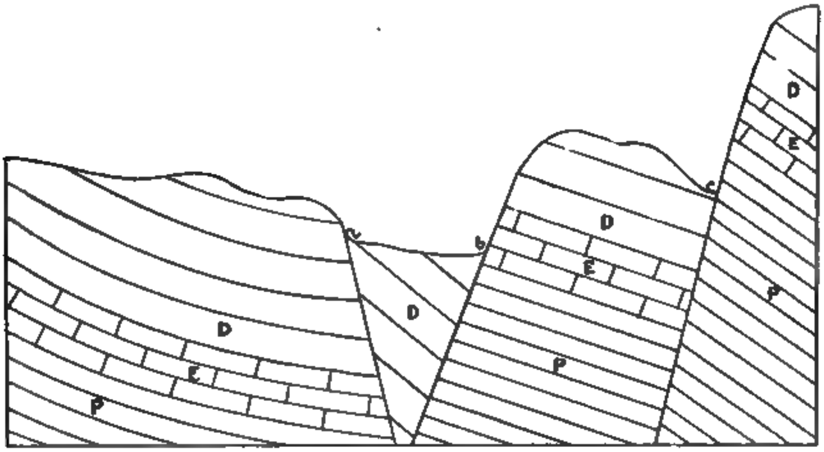


FIGURE 2.—IDEAL RESULT OF ASCENDENCY OF FAULTING OVER EROSION

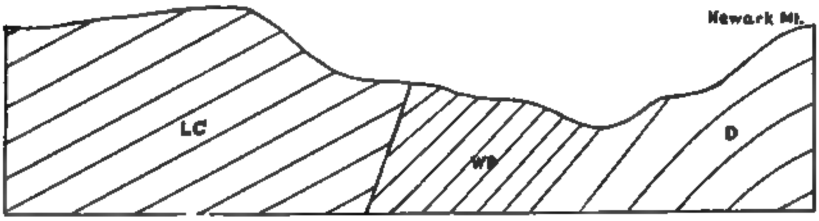


FIGURE 3.—FAULTING AT EUREKA, NEVADA

FIGURE 4.—FAULTING AT PIOCHE, NEVADA

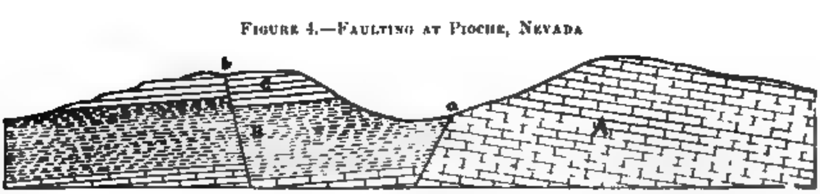


FIGURE 5.—FAULTING AT PIOCHE, NEVADA

EFFECTS OF FAULTING ON TOPOGRAPHY

FIGURE 1.—DIAGRAMMATIC SKETCH OF SIMPLE FAULT-SCARPS

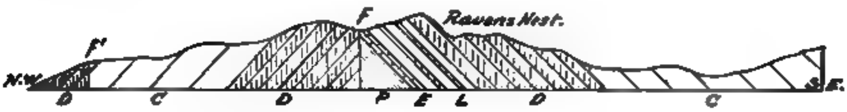


FIGURE 2. FAULTING OF THE PIÑON RANGE, NEVADA

FIGURE 3.—FAULTING OF THE HOUSE RANGE, UTAH

FIGURE 4.—CROSS-SECTION OF THE FUNERAL RANGE, CALIFORNIA

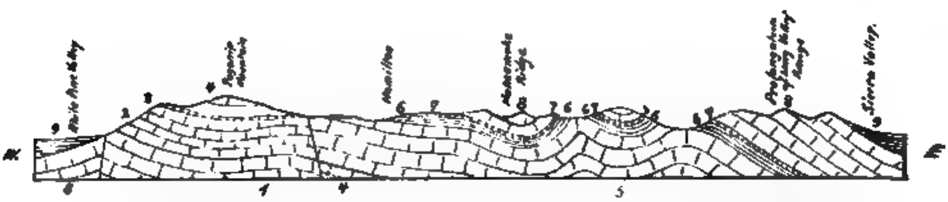


FIGURE 5.—CROSS-SECTION OF THE LONG VALLEY AND WHITE PINE RANGES

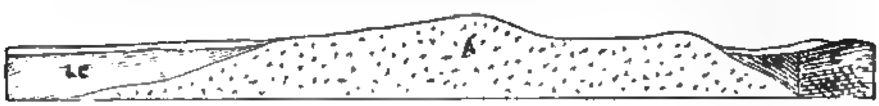


FIGURE 6.—CROSS-SECTION OF HUMBOLDT RANGE

EFFECTS OF FAULTING (FIGURES 1, 2, AND 3) AND EFFECTS OF FOLDING (FIGURES 4, 5, AND 6) ON TOPOGRAPHY

PLATE 24.—*Effects of Faulting (Figures 1, 2, and 3) and Effects of Folding (Figures 4, 5, and 6) on Topography*

FIGURE 1.—Diagrammatic sketch of simple fault-scarps.

Drawing by Spurr from the perpendicular walls of Meadow Valley canyon, Nevada. Shows ascendency of faulting over erosion. Scale, 1 inch = about 40 feet.

FIGURE 2.—Faulting of the Piñon range, Nevada (after Walcott).

Monograph XX, U. S. Geological Survey, page 201. Shows ascendency of erosion over faulting.

P = Pogonip limestone (Silurian); E = Eureka quartzite (Silurian); L = Lone Mountain limestone (Silurian); D = Devonian limestone; C = Carboniferous quartzites; F = erosion fault-gulch; F′ = fault with no effect on topography.

FIGURE 3.—Faulting of the House range, Utah (after Gilbert).

U. S. Geographical Surveys West of the One Hundredth Meridian, volume iii, page 27. Shows ascendency of erosion over faulting. Fault with no effect on topography. On superficial observation apparently a reversed erosion fault-scarp. Scale, 1 inch = about 5,000 feet.

FIGURE 4.—Cross-section of the Funeral range, California (Spurr).

The mountains are made up of Tertiary sediments and volcanics. The diagram shows ascendency of folding over erosion. Anticlinal ridges and synclinal valleys of deformation. Scale, 1 inch = about 3¼ miles.

FIGURE 5.—Cross-section of the Long Valley and White Pine ranges (Spurr).

This cross-section was taken in the latitude of the White Pine mining district, and shows ascendency of erosion over folding. Synclinal and monoclinal ridges of erosion and anticlinal valleys of erosion. Scale, 1 inch = 4 miles.

1 = Cambrian limestone; 2 = Pogonip limestone (Silurian); 3 = Eureka quartzite (Silurian); 4 = Lone Mountain limestone (Silurian); 5 = Nevada limestone (Devonian); 6 = White Pine shales (Devonian); 7 = Diamond Peak quartzite (Coal Measures); 8 = Coal Measure limestone; 9 = valley wash (Pleistocene).

FIGURE 6.—Cross-section of Humboldt range (after King):

Explorations of Fortieth Parallel, Atlas, General Sections Sheet. Shows ascendency of erosion over folding. Anticlinal ridge of erosion. A = Archean; L C = Lower Carboniferous; U C = Upper Carboniferous. Scale, 1 inch = 4 miles.

PLATE 25.—*Cross-sections of typical Basin Ranges*

FIGURE 1.—East-west section of Quinn Canyon and Grant ranges.

Advanced stage of ascendency of erosion over deformation. Synclinal ridges and anticlinal valleys of erosion. Scale, 1 inch = about 3½ miles.

1 = Cambrian limestones; 2 = Pogonip limestone (Silurian); 3 = Eureka quartzite (Silurian); 4 = massive limestones, probably including both Silurian and Devonian; 5 = intrusive granitic rocks; 6 = extrusive rhyolites; 7 = valley wash (Pleistocene).

FIGURE 2.—East-west section of Spring Mountain range.

Ascendency of erosion over deformation. Synclinal ridge of erosion. The strata in this figure are massive limestones, chiefly Carboniferous, but very likely with Devonian and possibly Silurian in the lower portions. Scale, 1 inch = about 3½ miles.

FIGURE 3.—North-south section of Spring Mountain range.

Advanced stage of ascendency of erosion over deformation, with probable recent deformation superadded. Slight normal erosion fault-scarp; fault with no effect on topography; probable later anticlinal arch of deformation. Scale, 1 inch = about 3½ miles.

1 = Cambrian quartzites chiefly; 2 = Cambrian limestones; 3 = Silurian limestones; 4 = massive limestones, chiefly Carboniferous, but very likely extending through the Devonian into the Silurian, possibly into the Cambrian; 5 = valley wash (Pleistocene).

FIGURE 4.—East-west section of Mormon range

This section is taken at the northern end of the range. Ascendency of deformation over erosion. Anticlinal ridge of deformation, bearing a growing anticlinal valley on its crest. Scale, 1 inch = about 3½ miles.

1 = Carboniferous limestones; 2 = chiefly ancient folded acid volcanics and derived sediments (early Tertiary); 3 = little folded conglomerates and sandstones, with lavas (late Tertiary-Pleistocene).

FIGURE 5.—East-west section of Hot Creek range.

This section is taken at Hot creek. Special relation of deformation and erosion. The deformed strata have been protected from erosion by a covering of lava, only lately stripped off in places. Probable anticlinal ridge of deformation, and simple fault-scarps (*a*, *c*). Erosion fault-gulch (*b*).

1 = Pogonip limestone (Silurian); 2 = Eureka quartzite (Silurian); 3 = Upper Silurian shales and thin bedded limestones, corresponding to the Lone Mountain formation of Eureka; 4 = massive rhyolite; 5 = stratified older gravels (Pliocene); 6 = valley wash (Pleistocene).

FIGURE 1.—EAST-WEST SECTION OF QUINN CANYON AND GRANT RANGES

W. E.

FIGURE 2.—EAST-WEST SECTION OF SPRING MOUNTAIN RANGE

N. S.

FIGURE 3.—NORTH-SOUTH SECTION OF SPRING MOUNTAIN RANGE

W. E.

FIGURE 4.—EAST-WEST SECTION OF MORMON RANGE

W. E.

FIGURE 5.—EAST-WEST SECTION OF HOT CREEK RANGE

CROSS-SECTIONS OF TYPICAL BASIN RANGE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 271-300 JUNE 17, 1901

BROAD VALLEYS OF THE CORDILLERAS

BY N. S. SHALER

(Presented before the Society December 29, 1900)

CONTENTS

INTRODUCTION

In the following pages I propose to set forth the results of observations made in that part of the Cordilleran system which lies within the limits of the United States, excluding Alaska. The main end in view is to exhibit the history of the erosive processes in that region with reference to successive changes in climate during the later geological periods. Incidentally, reference will be made to the general conditions of erosion in mountainous countries and to the effects of alternating plentiful and scanty rainfall on the forms of valleys as well as the influence of the volcanic ejections which have occurred in the Cordilleras since the existing topography began to be developed.

Although the results of the inquiries which are recorded below represent a considerable amount of labor, including journeys aggregating a distance of more than 10,000 miles within the area above noted, they must be regarded as in a great measure tentative. The field of the inquiry is large and, while the facts set forth are tolerably clear, the conclusions to be drawn from them are open to debate. It is, moreover, evident that the matter deserves a more extended study. This paper undertakes little more than to indicate in general the value of the

results which may in time be attained by following certain series of phenomena exhibited in the valleys of the Cordilleran district.

State of the Valleys

It has often been observed that the valleys of the larger streams in many parts of the Cordilleras—at least within the limits of the United States—are prevailingly of remarkable width, their aspect being often that of broad plains, sloping gently from the bases of the mountains on either side to the rivers which drain them. These streams are usually without definite banks and not directly controlled, as regards their positions, by the bed rocks of the mountain ranges. Here and there, though exceptionally, this great area exhibits streams which have carved very deep canyons—a type of valleys in singular contrast to the more common broad vales. There is no definite series connecting these deeply carved, narrow valleys with those of the broad form. The two groups are, indeed, sharply contrasted; the variety of intermediate forms seems to indicate some essential difference in their histories.

The valleys of the broad type are formed of two very distinct topographical elements—the mountain walls on either side and the slopes locally termed "benches," which extend, with gentle declivities, from the base of their steeps to the central part of the trough. The mountains exhibit the usual range in form, their torrent valleys above the zone of gentle slopes having the normal shapes due to the incising action of swift-flowing streams. Except that the gently sloping surfaces characteristic of the broad vales often penetrate for some miles upward into the troughs of these lesser streams, they in no noticeable way differ from those similarly placed in other elevated districts. Passing from the steep, mountainous country into the vale, there is commonly an abrupt change in the angle of the slopes. They decline to an average of probably less than 100 feet to the mile. Although this slope is often quite uniform for the distance—it may be of several miles—there is commonly a rather gradual decline in the grade, so that it passes from about 2 feet in 100 next the rocky borders to less than one-half foot in that distance in the central part of the vale. The surface of these sloping bottoms of the broad valleys is little varied, except where they are intersected by the greater streams which make their way across them from the torrent zone to the main water-courses. At these points the benches are traversed by valleys, usually of considerable width, which are occupied by local deposits evidently of detrital origin and of lesser declivity than those they intersect as well as of more recent formation.

Although in most instances the valleys we are considering are un-

broken by isolated eminences of a mountainous nature, it not infrequently happens that low peaks protrude above the generally even surface and occasionally a considerable mountain range breaks their slopes. Here and there, especially when the valleys are of the widest form, volcanic peaks occur, commonly as degraded stocks—that is, the remnants of cones. In fact these structures, though not common, are among the characteristic features of these broad vales They are irregularly distributed, sometimes lying in the central part of the troughs; again, perhaps most commonly, near their borders or even in the marginal parts of the mountain ranges that constitute the divides between the drainage basins.

Noting the evident likeness of these broad valleys to those of rivers in a country brought near to its baselevel of erosion, the observer is at first led to the supposition that they are but extreme instances of widened drainage troughs, wherein, as usual, the cutting streams in their windings have excavated very wide vales. A little observation shows that this explanation is insufficient for the reason that nowhere are the watercourses now at work on the hard bed rocks of the country, access to them being made impossible by the long detrital slopes on either side. These slopes, though they are made of rather incoherent detritus, are never cut into escarpments of any considerable height. They control the drainage and are not controlled by it. Finding, as we do, many instances of valleys 10 miles or more in width and 50 or more in length, with their rivers everywhere defended by detritus from their ordinary incising work, we are forced to conclude that these vales are not widening by the swingings of their drainage channels and the successive excavations which are thus induced.

The next working hypothesis which may be adduced is that these broad valleys, after having been excavated to a much greater depth than they now exhibit, have, by some process of warping or tilting of the region in which they lie, been converted into lakes, and that their sloping central parts are made up of lacustrine deposits. That such is not generally the case is indicated, as will be shown further on, by the character of the deposits, but even more clearly by the topographic shape of the materials. Save in such instances as are afforded by the extinct lakes of the Bonneville group, where there are characteristic shorelines, the lacustrine hypothesis, though frequently applied, is usually inadmissible. This is indicated by the facts now to be set forth.

Where we trace the margins of the slopes or benches to their contact with the bordering ranges we nowhere find distinct beach terraces such as are so well exhibited about the Utah lakes. It can not be assumed that such terraces once existed, but have been destroyed, for such ruining action would have greatly changed the surface of the slopes, which

still extend in admirable continuity up to the foot of the rocky steeps. Moreover, if we follow up the lines of contact of the slopes with the ranges toward the head of any of the main branches of a river system such as that of the Missouri, we find that these lines rise, though it may be at a less rate, with the general ascent of the valleys. To suppose that the margins of the slopes marked, even in a general way, the shores of extinct lakes would require an hypothesis of secondary tilting for each valley such as would be quite inadmissible. Thus, while here and there lacustrine deposition has undoubtedly played some part in the development of the existing forms of these troughs, it can not be held that the process has been the main agent in giving them their shape. Further reasons for dismissing this hypothesis appear when we examine into the constitution of the deposits which underlie the approximately level parts of these valleys.

Structure of the Valley Deposits

Owing to the fact that the streams which drain the valleys of the broad type do not, to any considerable extent, attack the deposits by which they flow, there are very few natural sections of value to the observer. The surface of the beds is, in most parts of the field, covered with a soil in which more or less angular pebbles abound. At many points the burrowing insects and mammals have brought the finer debris which originally lay between the pebbles within a few feet of the top to the surface, so that it has been blown away by the wind. By the growth of vegetation, a part of the decomposed rock has been brought to the air, where, after the decay of the plants, it is likewise thus swept off. The result of these deportative actions has been to so far concentrate the pebbly material of the soil that in the more arid portions of the Cordilleras the ground is often completely covered with coarse fragments. Where quantities of earthy matter have thus been removed in the form of dust it is common to find considerable deposits of the wind-blown material along the banks of the streams having a thickness of from 3 to 6 feet. The deposition takes place because the speed of the wind is lessened in the tangle of vegetation which grows in the humid belt near the streams. A portion of this blown debris finds its way up into the mountains, where it comes temporarily to rest in the forests and grassed fields. Much of it appears to journey on in the prevailing westerly winds until it passes beyond the eastern border of the mountain system.

Penetrating beneath the concentration of debris produced in the manner above noted, we find in the ordinary limited sections such as are afforded by railway cuttings and irrigation ditches or the occasional shaft

wells concerning which information can be had, the subjacent beds commonly made up of fragmental materials in general as appears at the surface. The pebbles in these beds are usually not much water-worn, except where they have evidently been transported from a considerable distance by the mountain torrents and accumulated on their detrital areas. In such positions they have the character common to such pebbles. In all the instances where I have been able to identify the source of these fragments they have come from the rocks of the neighboring mountains. Although the observations I have made are limited, they go to show that the proportion of materials coarse enough to be termed pebbly is large, commonly more than three-fourths of the mass, and that these pebbles are much decayed.

As regards the size and distribution of the fragments, they are clearly larger the nearer they are to the bases of the mountain walls. There is, indeed, a tolerably uniform decrease in their size as they lie farther away from the highest part of the slopes; yet it is not uncommon to find fragments as much as a foot in diameter at a distance of 2 or 3 miles from the source whence they came. The extent to which they are decayed usually increases as they lie farther out toward the center of the valley. Where the rocks are granitic and of a rather perishable character, as about the Silver Bow river, near Butte, Montana, the coarse element in the deposit does not commonly extend for any considerable distance from the foot of the mountains. In these conditions the material of the slopes ordinarily consists of the disintegrated rock of which the crystals are sufficiently well preserved to warrant the term arkose being applied to the mass. The formation of these peculiar beds is greatly favored, if, indeed, it is not mainly brought about, by certain species of ants which abound in nearly all parts of the Cordilleras. These creatures accumulate upon their hills quantities of the fragments which have become loosened by the decay of the crystalline rocks. It is not uncommon to find in one of their heaps as much as 2 or 3 cubic feet of such debris. At several places, particularly in Arizona, I have noted, over large areas, as many as 50 of these hills to the acre of ground, with the result that in a single square mile there may be several hundred cubic yards of material ready to be swept away by a torrential rain, to be laid down in the lower parts of the valley.

It may be incidentally noted that one of these species of ants which particularly abounds in the southern part of the Cordilleras has another habit which facilitates soil erosion both by rain and wind. This insect completely removes the grass and other lowly vegetation over a circle from 10 to 20 feet in diameter, in the center of which lies the nest or hill. As the roots of the plants are extirpated the ground is deprived of its

natural protection, and, as the circles in question are often so distributed that their margins are almost in contact, the result is that the sheets of water which flow over the ground when a torrential rain, the so-called "cloud-burst," occurs are likely to find the earth quite without its natural protection against erosion.

The only place where I have been able to make any satisfactory observations as to the structure of the deposits of the detrital slopes of the valleys at a depth of more than 30 feet below the surface is in the region about Butte, Montana. At that point a number of shafts have been sunk through the debris which fills the valley of the Silver Bow river. These shafts are all abandoned, so that the only information concerning them has been derived from the waste about the pit mouths and from the statements of those who remember something of what was encountered in the work of sinking them. It seems tolerably certain that the deepest of those shafts sunk near the center of the valley slopes, which are here about 2 miles wide, failed to attain the bed rock at a depth of between 3 and 4 hundred feet, and that the material passed through was principally of a nature approximating to arkose, with occasional pebbles composed of the harder dikes which intersect the crystalline rocks of the country. At other points in the valleys of the Upper Missouri system, especially in that of the Stinking Water, now renamed the Ruby, borings which I had a chance to observe indicated that the material to a depth of 50 feet and at a distance of about 4 miles from the Old Baldy section of the Tobacco Root range contained coarse pebbles. Various railway and irrigation ditch sections from northern Montana to central Arizona clearly show that this pebbly nature is common to the deposit.

At some points this detritus forming the benches of the valley, when it is of an arkose nature, has become cemented in so firm a manner that it is readily mistaken for granite. In two instances I have known this mistake made by competent mining experts, who were not to be persuaded of their error until they were shown that ordinary gravel lay beneath the firm beds. These recomposed crystalline rocks appear in all cases to occur near the foot of the mountains in places where the grains of decayed granitic rocks have not been much rounded or deprived of that part of their matter which was readily soluble.

So far as the inadequate sections give information concerning the materials underlying the general surface of the valley, they indicate, as before noted, that the deposits consist of debris brought from the adjacent mountains. This mixture of clay, sand, pebbles, and larger fragments is rudely stratified; the bedding is irregular and often scarcely traceable, but has an evident dip toward the center of the valley in which the deposit

lies. Very often we find a mass of ordinary torrent waste intercalated in the body of less transported material. These accumulations sometimes occur where they can not be certainly referred to any neighboring torrent valley, yet they clearly are the product of some mountain stream which has shifted its position since the pebbles were laid down. In the depressions of the slopes through which the mountain streams pass on their way to the main rivers I have found, notably in the valley of the Ruby river of Montana, a class of materials in marked contrast with those which make up the unconsolidated beds of the main valleys. Thus in pits sunk to test the value of auriferous gravels at Alder creek, in Madison county, Montana, the deposits of a pebbly nature constituting the detrital cone of the stream which lies in a wide depression of the principal slope of the vale have a thickness of from 20 to 60 feet, their depth increasing toward the center of the valley. Beneath this pebbly bed, with a very sharp transition, we come upon a grayish white clayey deposit of an absolutely homogeneous character, which has been bored through to the depth of 90 feet without finding bottom. This clay-like matter continues upward in the flat-bottomed gulch occupied by Alder creek for about 5 miles from the mouth of the canyon; at 3 miles above that point it has a thickness of over 100 feet.

Although occasional fossils are found in the torrent gravels which have been formed since the Glacial period, they give no trustworthy evidence as to the age of the deposits. I have gathered from Alder gulch, within the upper limits of the detrital cone, near to or upon the foundation of volcanic ash before referred to, several disjointed fragments of the skeleton of an elephant and teeth of *Elephas primigenius*, but in the same section have found a part of the jaw of a morosaurus. As there are evidently no Cretaceous beds now existing in the valley of that creek, we may presume that this latter fossil came from deposits that have been completely removed from the district. So far as I am aware, no fossils have been found in the probably more ancient taluses of the broad valleys.

As yet the nature and origin of the Alder Gulch clay is somewhat uncertain. The components of the mass are so far decayed that they can not be clearly identified. The facts, however, warrant the supposition that the mass was derived from a basic, volcanic ash. These facts are as follows: The clay is quite unmixed with pebbles or even distinct grains of sand; it is not even stained with iron as an ordinary sedimentary clay made in such a position would be. It exhibits no distinct stratification. It does not become coarser on approaching the mountain or even in the upper parts of the canyon of Alder creek. Moreover, on the westerly side of that stream, near the mouth of Granite creek, it is immediately overlaid by lava flows which have certainly at

one time overspread all of the valley of that stream. Not only on either side of the channel lie the dissected fragments of an extensive *mesa* of basalt, but there are the stocks of minor cones within a radius of 5 miles which were evidently in eruption long after the older clay-like material had been much dissected by the torrents that traverse it. These conditions make it reasonable to suppose that the clays above referred to have been derived from the decomposition of volcanic ash accumulated when it fell or washed into position by the rains which commonly attend eruptions.

It appears clear that these ash beds were accumulated during a volcanic outbreak which followed the construction of the main benches of the valley. They evidently do not extend beneath the general surface of the benches at least in those parts of the area adjacent to the mountains, though they are probably to be found in the central part of the troughs. The deposit which lies beneath Alder creek has been traced by borings almost out to Ruby river, a distance of 3 miles from the mountain walls. On either side it appears to come into contact with, but not to pass under, the material of the benches. It thus appears likely that the ash must have been laid down on the general surface of the country and afterward swept into the channel of the creek. It is certain that none of it is now visible on the levels above the stream bed, and that it is covered by a thick layer of debris comprised of the rocks which make up the mass of the neighboring mountains.

The fact that at Alder creek the rock channel has been so deeply filled that at 7 miles up from its junction with Ruby river its present level is over 100 feet above its original bed, and that an even deeper infilling has taken place in the Silver Bow valley near the head of a small branch of the river, shows clearly that very great changes have taken place in relatively modern times in the details of the form of the valleys of the Upper Missouri district. I now propose to consider what are the real shapes of these vales beneath the masses of detritus with which they have become thus occluded. I have already noted the fact that the valley deposits, from the lack of natural sections, most effectively mask the shape of the bed-rock outlines. At only one point, namely, in the city of Butte, have I been able to find any artificial cuts through the upper parts of the slopes that reach the bed rock. In that town, however, many openings, especially those for a system of sewerage, have disclosed facts of much interest, which, taken with other bits of information, enable us to construct a tolerable picture at least locally true of the hidden bed-rock floors of these troughs.

It is first to be noted that the detrital slope on which the city of Butte is built extends from near the top of a degraded mountain to Silver Bow

creek, a distance of about 2 miles. In the angle of its declivity, its general form, and the character of the material next the surface it is essentially like the other benches of the Cordilleran valley. It has the normal width of these slope benches in valleys occupied by streams of like volume. Left in its undisturbed state, it would have been classed with the other like structures. The only peculiar feature is found in the more than usual readiness with which the granitic and volcanic rocks of the ridge decay. These rocks disintegrate at a considerably greater rate than the average of the mountain-building formations of the area, with the result that the Butte ridge has evidently lost in height more rapidly than the other divides of this region. The only effect of these local conditions has been to hasten the processes by which the valley was formed, so that the trough is somewhat broader than it would otherwise have been.

The plentiful openings which have been made in the talus slopes beneath Butte show that the bed rocks form a tolerably continuous incline in which there are no conspicuous departures from a regularly inclined surface to a line about 1,000 feet from the general position of Silver Bow creek; there they turn rather suddenly downward. On the opposite side of the stream toward the now bald granitic hill known as Timber butte the few pits that have been sunk indicate a similar position of the bed rocks. The gorge into which these slopes of the firm rocks decline apparently has a width of one-half mile. Its depth is uncertain, but as it is clearly at least 400 feet deep in the small branch of the creek that lies to the east of the town between it and the Continental divide, we may assume a considerably greater depth of the buried gorge on the line of this cross-section above mentioned. Assuming that this buried canyon has the slope of the walls continued downward in the form of a V and with the steepness they have near their margin, it is likely that the bed of the ancient stream is at least 600 feet below the present course of its waters.

A careful inspection of the Silver Bow valley from the canyon on the west to the head of the streams that drain it warrants the supposition that the same form of the bed rocks exists in all its parts. Everywhere the numerous prospect holes made in the search for ore-bearing veins reveal the presence of the crystallines beneath from 5 to 50 feet of surface debris out to a line from 1 to 2 miles beyond the mountain steeps, and then a swift descent of the under rocks to a narrow and deep channel. As to the nature of the filling of this deep gorge we have no certain information. It is said, however, that wells near the stream have encountered a whitish clay at the depth of 30 feet which may be of volcanic origin. Assuming that the valley of the Silver Bow has been thus deeply excavated and refilled, the question arises whether this cavity

could have been produced by other than river action. For reasons already given it seems impossible that these channels should have been formed by differential warping, for if such were the case the movement would have had to follow the paths of the much-branched valley; moreover, the form of the central gorges of these troughs is altogether inconsistent with the supposition that they are due to such movements. We have thus to believe that the stream beds of this area were, at no geologically distant date, several hundred, perhaps a thousand, feet lower than they are at present.

The passage from the broad valley of the upper Silver Bow to the narrow gorge by which the waters of the basin find their exit clearly demands explanation. This may possibly be found in the fact that the rocks through which this channel is cut evidently decay rather slowly, and so developed a narrow canyon gorge. It is, however, not unlikely that there has been here, as elsewhere in the Cordilleras, a recent change in the path of escape of the stream by which a new way of escape was provided, so that the higher portion of the vale was formed or at least outlined with one baselevel of drainage, and the lower at another such level. This is, however, a question of detail that cannot well be here considered.

In the part of the Ruby River valley near Alder creek the evidence obtained from borings, as before noted, together with that gained by an inspection of the surface features of that area, shows conditions of the ancient topography substantially the same as those found near Butte. The sloping platform of the ancient rocks on the northern side of the vale is evidently continued out for an unknown distance toward the center of the valley. Through it Alder Creek canyon extends with an unknown depth. The same appears to be the case with other similar lateral gorges. At various other points in the broad valleys of the Upper Missouri River system chance excavations show a like extension of the slope of bed-rock for some distance out from the mountains toward the streams. None of these sections afford any clear indication of the depth of the central trough, but in all of the instances observed the rate of the decline is so great that the depth in the middle of the trough must be profound.

The above-noted very limited observations as to the under form of the Cordilleran broad valleys are of themselves clearly insufficient to warrant any general conclusions as to the existence of a like topography in other parts of the region. There are, however, certain groups of facts which enable us, with qualifications to be noted, to extend the conclusions, with varying certainty, over the whole of this field. First let us note that the valleys in question, though the walls of their mountain

borders are remarkably straight, not infrequently have outliers which lie a little way removed toward the centers of the troughs. These are of the harder rocks, such as are found in a region of varied structure. It is a noticeable fact that scarcely any of these isolated masses occur far out from the main ranges. Very seldom in valleys 10 miles in width do they appear at more than a mile from the upper margin of the valley slopes. Now, it may be assumed that in any normal process of valley erosion producing basins 10 to 20 miles in width there must have been many outlying eminences left on its floor, of which the summits would have remained at a relatively great height above the bottom of the excavation. We should, for instance, in vales such as these were before they were in large part filled, expect to find, even near their central parts, outlying elevations some thousands of feet in height above the level of the drainage channel. As above remarked, except along the margins of these wide expanses, we do not find any trace of these normal remainders of erosion where it acts on rocks of diverse resistance, such as are found in almost all parts of the region we are considering. These topographic outliers may be seen in all conditions of occlusion by the valley beds, from the state in which the rocks connecting them with the main ranges are still uncovered to that where only the very tips of the summits break the surface of the detrital slopes. Although this kind of evidence clearly indicates the very great original depth of these valleys before the process of obstruction began, it does not afford any sufficient basis on which to reckon their original depth in terms of feet or even in miles. A study of the facts in the field, however, brings the observer to the hypothesis that in the average of these vales—as, for instance, that of the Jefferson or Gallatin river—the amount of the infilling must amount to not less than 5,000 feet.

The evidence goes to show that the erosion of the valleys of the Rocky mountains was accomplished with exceptional rapidity. This is well indicated by the fact that the remains of ancient river channels, now filled with gravels, lie at a remarkable height above the present levels of the main streams. Thus, on the mountain known as "Old Baldy," in Madison county, Montana, there are the fragments of several deep troughs, which were originally the seat of large mountain torrents, which are filled with river gravels to the depth of over 200 feet. These gravels are of so recent an aspect that they have been mapped on the United States Geological Survey sheets as glacial drift, a mistake which was most natural for the reason that it is only recently that extensive excavations, in searching for placer gold, have revealed their true character. The unmetamorphosed condition of these gravels makes it seem likely that they are of no older than Tertiary age; yet since they were deposited

the Madison and the Ruby rivers, at the base of the mountain, have cut down 3,000 feet to the present level of these streams, and also for the unknown depth of the troughs that lie below the detritus that partly fills the valleys. The total erosion can not well be less than 6,000 feet and may very much exceed that estimate, yet it has apparently been accomplished in geologically modern times, certainly since the Cretaceous period. This instance of high lying, apparently recent gravels is but one of many that could be cited from the region about the headwaters of the Missouri. They occur at a number of points about the Madison river and elsewhere.

Although we have to estimate the original depth of the valleys as surprisingly great, the estimate does not have to go so far as it would if we were to neglect the broad shoulders or bed-rock slopes which, we have reason, as at Butte, to suppose, commonly lie beneath the lateral parts of the detrital accumulations. If we should suppose the declivities of one of the broader of these troughs to be carried downward as continuous slopes to the center of the excavation, we would have to reckon an almost impossibly strong topography. On this basis we should have valleys equal to, if not exceeding, any now existing on this sphere. As it is, we cannot well escape the conclusion that some of these vales have the sites of their original streams below the level of the sea; that if the debris that now fills them were removed they would have more than twice their existing depth.

An evident objection to the supposition that these valleys once had the great depth which is here assigned to them is found in the fact that the streams which drain them sometimes pass over bed rocks at a level which is not far from the present beds of the streams that traverse them. Thus the Missouri at Great Falls flows on the bed rock, and like conditions may be found elsewhere. In answer to this objection it may be said that these valleys are evidently very ancient, and that extensive local warpings have clearly taken place since they were formed. Moreover, in such instances as that of the falls of the Missouri it is possible that the stream has been so far displaced by the infilling of its original channel as to flow at some distance from the path it followed when the channels were excavated.

Method of Infilling of the broad Valleys

We have now to consider the conditions which have led to the deposition of the beds that have so far occluded the greater part of the Cordilleran valleys within the limits of the United States. Incidentally we have noted that these accumulations were not to any considerable ex-

tent formed in lakes. There are, however, various possible explanations of the infilling action which need to be examined. In approaching the inquiry it is well to see clearly that the main question is as to the ways in which the detritus swept from the fields of erosion in the mountain ranges has come to be retained in the valleys near its sources, or, in other words, how the disturbance in the normal balance between the agents which serve to break up rock materials and start them downward and those which provide for their distant transportation has been disturbed. It is evident that while these valleys were in process of excavation the rivers were competent to carry away all the debris that came to them, and that for a long time they have been unable to effect this work. The question is as to what has brought about this change.

There are several diverse influences which may serve to diminish the capacity of streams for carrying detritus to the sea. These may be stated as follows: First, the surface over which they flow may be so far lowered that the grades from the base line upward may be too slight to give the rivers the speed required for carrying the amount of debris that is brought down to them by the torrents; second, by a differential movement of the lands the valleys may be so tilted that their outlets are disturbed and their exit grades diminished; third, by change in the adjustments of the rainfall and of the atmospheric decay of the rocks, which goes far to determine its erosive value, the amount of material brought down from the heights into the valleys may much exceed that which the streams can bear away to the lower country or to the sea, and the state of this eroded material may be such that it is not readily moved by the rivers.

As for the first of the working hypotheses above suggested, it may be said that the general subsidence of the Cordilleras, or possibly a rise of the sealevel, or both movements combined, has probably brought the bed-rock floors of these valleys nearer to the ocean level than they were when the process of excavation was completed. Yet these troughs remain, in most instances, so high and their grades are so steep, as compared with others which have not become occluded, that we can not regard any hypothesis dependent on a change of grade as in itself sufficient to account for the facts. As for the second suggestion, it may again be said that it demands a complicated series of movements in the way of warping. It will hereafter be noted that such local movements due to isostacy have probably taken place, and that their effect has been to bring the bottoms of many of the valleys to a lower level than they occupied when they were in process of excavation; but these movements are a consequence of the infilling and not the cause of that process. Though they helped to extend the work after it was otherwise

begun, they could not have instituted the deposition. We have now to consider the third of these possible sources of the change in conditions. as we shall find it provides a more adequate explanation than the others.

As is well known, in a normal river valley the primary agents of erosion deliver to the streams no more broken-up rock than can be conveyed by the torrents to the lower ground and sent away in solution, in suspension, or by working along on the bottom of the rivers. On the substantial completion of this transportative process the access of the eroding waters to the bed rocks depends. In so far as the eroded material halts in its downward course, the work of erosion is lessened or arrested. In almost all valleys there are local and temporary stoppages of the debris, each of which diminishes the cutting action of the streams, but these halts in the downward course of the waste commonly are not long enduring, nor do they more than qualify and lessen the erosive work. If, however, from any cause, the amount of debris sent from the heights to the vales is greatly increased or the capacity of the river to bear it away is lessened, then the valley receives more detritus than can be borne away. It is, indeed, evident that in most river valleys, as distinguished from the channels of torrents, the amount of addition of detritus required to effect the change from degradation to aggradation is but small, for rivers normally are so adjusted that with the existing slopes they are able to do no more than keep their channels clear. If they cut down more rapidly than the summits descend, the slopes steepen and the quantity of debris is increased; if by excess in the supply of debris they cut more slowly, then the divides become lowered more rapidly than the stream beds, the declivities of the torrents are thereby lessened, and the delivery of detritus to the center of the valley goes forward with less rapidity. The question now before us is as to the ways in which this delicately adjusted state of a normal river may be so interfered with that it can no longer keep its way free.

The most immediate cause of clogging of a valley is to be found in the sudden importation of waste by other than torrent action. Thus glaciers or landslides may sweep detritus from the high country and bring about the embarrassment of drainage which is noted in the New England district and elsewhere. Again, showers of volcanic ash or more locally lava flows may fill the trough to a great depth. In the field we are considering glacial action has had no significant part in the accumulation of debris in the valleys except it may be in certain limited fields, as in central Colorado. On the other hand, the outbreaks of volcanic materials have undoubtedly done much in the way of accumulating materials which the streams were unable to remove. Where the igneous matter is in the form of lava the blocking of the valley may be so com-

plete that the stream is forced into other channels. When the ejections are as ash the embarrassment of the drainage may be more extended and nearly as complete, for the reason that the dust, though spread over a wide area, is likely to be rapidly swept away to the low ground by the rain in such quantities that when cemented in the form of tuff the rivers can not bear it away. Where a region is the seat of extensive and long-continued volcanic activity the original topography may become entirely hidden, as is the case in the great area of the Columbia River ash and lava fields, so that a new drainage system has to be developed.

Although in certain parts of the Cordilleran district volcanic ejections of ash or lava may have had a considerable share in forming the accumulations of the ordinary broad valleys, the evidence goes to show that they have not been the principal agent in this work. The fact that the ash deposits at Alder gulch lie in a channel cut through the slopes by a mountain torrent, and that they do not extend under the ordinary detritus of those slopes, indicates that the only accumulation of fragmentary volcanic matter of which I have been able to trace the history came too late to have had any decided effect on the filling process. Moreover, very many sections, though none of them except those near Butte are of any great depth, go to show that the mass of the detrital slopes are of ordinary water-worn detritus. We may therefore consider volcanic waste as an element other than controlling in the process of deposition, and we are forced to seek the principal factor in changes in the quantity and distribution of rainfall.

So far as I have been able to find the normal mountain valleys of the world, those in which the streams which are still excavating their beds appear to be generally limited to those areas in which the rainfall is considerable and rather uniformly distributed, while the broad type, such as we are considering, is common in regions where the precipitation is scanty and irregular, where it takes on the character common in partly arid countries of torrential rains so local and violent as to receive the name of "cloud-bursts." There are many reasons why the difference in the quantity and order of the precipitation should produce a wide diversity in the amount of debris brought down by mountain torrents into a valley. As this matter has not, so far as I have learned, been set forth, I shall give it a somewhat extended presentation.

First let us note that the degradation of a mountainous country is likely to be hindered by a thick coating of vegetation, for such a covering tends to prevent the access of frost. Moreover, the joints and other interstices of the rocks are kept continually full of water, and thus in part protect it from the access of air, while in arid conditions they are filled by the occasional rains, and as the water-table sinks, as it may do

to the extent of a hundred feet or more, the air is drawn down after it. The most important effect of the coating of vegetation is in protecting the surface from temporary torrents. An ordinarily firm mat of roots, even those of the grasses, will usually defend the earth from the heaviest streams that flow over it during the brief period when it is called on to withstand such an attack, while if not thus protected the earth would be excavated to the depth of several feet; furthermore, even where by chance a torrential rain manages to sweep a part of the protecting plants away, their debris is pretty certain to so far embarrass the work of the torrent that its load of detritus is likely to be in large part arrested on the way to the main river. It is, indeed, safe to say that the erosive effect of a given amount of water descending a torrent-making slope diminishes in a very rapid ratio with the increase in the thickness of the mat of vegetation. A virgin forest of the Appalachian type will, if its bed be fairly dry, detain a rainfall of as much as 3 inches falling in, say, one hour, and distribute the discharge over a day or more. Even the precipitation of the heaviest "cloud-burst" of the Cordilleras would be so far hindered in its downward movement that it would have little destructive effect.

Where, as in nearly all parts of our Cordilleras, local rainfalls not infrequently occur to an amount of several inches an hour the scanty vegetation that prevails in that area is incompetent, in any large measure, to restrain erosion. The result is that a sheet of water sweeps down the steeps with such volume and speed that the loose material up to fragments a foot or more in diameter are swept into the torrent channels or, if the discharge be into a broad valley, far out on its slopes. I have never had an opportunity to observe a good example of these interesting floods, but from the accounts I have had of them from trustworthy observers and from an examination of their effects I am satisfied that the amount of debris which is by their action discharged into the broad valleys is very great, and that the process is one that has hardly any likeness in regions of considerable and uniform rainfall.

Although the contribution of debris to the detrital slopes of the valleys, as may be readily seen in the field, comes to them in part directly from the action of torrential rains, carrying the debris out onto their surfaces, the larger portion of the eroded material is delivered by way of the permanent torrent channels and disposed as detrital fans at their mouths. If the points of discharge of these torrents were permanently fixed, the debris thus brought into the main valleys would be heaped into a series of these fans, while in the spaces between the gulches there would be only the waste brought down from the steeps that face the valley—debris which did not pass through the torrent channels. In

fact, however, there is no such localized arrangement traceable. The detrital slopes have a remarkably even and continuous upper limit next the erosion faces, though they are commonly higher between the torrent mouths than elsewhere. This peculiarity is probably due to the fact that the positions of the mouths of the torrents are evidently liable to frequent changes, and that in the geologic periods during which these valley deposits have been accumulating this constant alteration would tend to effect an even distribution of the material brought down by the tributary streams.

The changes in the positions of the torrents are brought about in several different ways. Thus the process known as the robbing of one drainage basin by another is of very frequent occurrence in this region. Instances of it may be noted in almost any area that is attentively examined. Again, where, as in most mountainous districts, the strata have varied inclinations, the channels are led by the attitudes of the beds to change their positions as they work downward. Yet, further, the heaping up of debris in the center of a detrital fan tends to divert the streams to the margins of the steep delta, so that the range of the deposition is greatly extended. Moreover, the various tiltings to which the several areas have been subjected have doubtless served to change the course of these streams and the accumulation of their discharge. All these influences and probably others not yet discovered have served to bring about in course of time a tolerably even distribution of the materials brought down by the steep graded streams into the broad valleys.

Turning now to the main rivers which drain the valleys, let us consider what are the conditions of their action during the period when the greater part of the precipitation is in torrential rains. As it is characteristic of these rains to be very local, they often being limited to a few square miles of area, the amount of water they send into the rivers is too small to have much effect upon their volume or speed. Moreover, for the reason that the detrital materials of the valley are very open in structure they quickly absorb much of the flood, so that the reinforcement of the main stream is apt to be slight, while the water which comes to it is heavily charged with debris too coarse for the slower movement to bear away. The result of these conditions is that the streams in the center of the broad valleys tend to aggrade their channels, while in normal rivers the contributions of detritus brought to them by torrents come so slowly to their beds that the materials have a chance to decay and break up to a state where they are readily transported in solution, in suspension, or by being rolled along the bottoms. In these abnormal streams the excessive discharge from the torrents cannot be thus removed. As

soon as a river ceases to cut downward and begins to aggrade it passes a critical point in its history and begins at once rapidly to lose its capacity to deal with the obstructive matter that comes to it. In proportion as the bed rises, the rate of flow must diminish, with a consequent and rapid loss of capacity to erode or carry debris.

The degree of the obstruction of the channel of the main stream due to the causes above mentioned depends on the distance of the point where its tributaries emerge from the mountains into its valley. Where, as in the case of Alder creek, Madison county, Montana, the detrital fan is about 4 miles in length, the greater part of the coarse debris is in the existing regimen of the stream deposited on the slope, but little of it entering Ruby river. In the lower part of its course the creek has a fall of little less than 20 feet to the mile, and in its original condition it found a devious and much obstructed way through a dense growth of shrubby vegetation. It happens, however, that whenever a valley is narrow, as it commonly is at the point where its stream cuts through a range of mountains, the detrital fans are steep, and the discharge of waste into the channel goes on rapidly. In this case the effect is to increase the rate of shoaling of the river bed, so that by the consequent diminution of the current a deposit of coarse detritus is laid down in the stream bed. Occasionally above these narrowed parts of the troughs there occur considerable areas of swampy land.

The obstruction of the drainage of the broad valleys is in some measure effected by the action of the wind in bearing dust from the more arid parts of the area to the banks of the streams. It may be here briefly noted that this dust is impounded in the rank vegetation which is commonly developed as a selvage along the banks of the water-courses, forming a characteristic loose deposit. In the course of the frequent changes in the position of the channel this wind-borne waste is apt to be washed away, but it adds to the load of the overburdened stream and diminishes the efficiency of its work. On the detrital fans this accumulation of dust, partly by its direct obstructive effect and partly through its influence in promoting a dense growth of vegetation, tends to force the torrents into continued wanderings and thus to a wide distribution of the debris which they lay down.

On the basis above laid down we are led to construct a general hypothesis as to the condition which brought about the present aspect of the Cordilleran broad valleys. First we have to suppose an ancient long-continued period of normal river action in which deep valleys of the Alpine type were formed. Then a period, or rather a succession of periods, of aridity in which the rivers were brought into the abnormal state where they could not remove the debris which the torrents conveyed

to them. In this state the channels proceeded to fill and the detrital slopes to climb higher upon the sides of the mountains. Wherever by the erosive process a part of the lower slopes of the ranges came to have a gentle declivity the accumulating debris would mantle it over; where outlying peaks became islanded in the detrital deposits they continued to wear down until, if their original height were not too great, the slowly rising surface would overtop them.

It is evident from the sections seen at Butte and elsewhere that the mantle of detritus lying on the bed rock tends to preserve that rock from further decay. This is brought about by a simple process, one commonly occurring in all gravels made up of rocks that afford soluble material, such as iron or lime. This dissolved matter finds its way down upon the bed rock, and there cements the lower part of the detritus into a hard mass which is impervious to water. Whenever we attain this contact of the detritus with the crystalline rocks we find this protecting layer, with the result that decay does not seem readily to occur beneath it. It is otherwise with the materials of the valley deposits between the upper section, which is prevailingly very dry, and the cemented layer. In this zone the process of decomposition appears to be tolerably rapid, as is shown by the considerable discharge in the seeping springs that appear along the streams when the water is commonly much charged with lime and iron.

In the manner above noted we can perhaps account for the peculiar shoulders of the bed-rock valleys which, apparently in a somewhat general way, extend from the margin of the steep gorges to the foot of the exposed portion of the mountain ranges. The process of occlusion of the narrow steep-sided central part of the valley probably would go forward with such rapidity that the exposed cliffs would not be worn down so that they could become covered. As the deposit rose higher in the trough it would encounter gradual slopes on which the detrital coating would, even where thin, preserve the bed rocks from further decay. It is evident that with a slope of about 150 feet in the mile the materials of the benches are commonly able to keep their place so that any declivities of less inclination would be protected. In this way, as the erosion forced back the faces of the mountains the valley would be widened, the gain representing the advance in the decay of the mountain fronts down to the level where the detrital accumulations began to protect the rocks.

This view as to the way in which the broad valleys widen may help us to understand the peculiarly straight walls which the ranges that border them present. As before noted, the generally rectilinear aspect of these mountain fronts demands explanation. It is, indeed, as striking an element as is the width of those vales. The feature may be due,

at least in part, to conditions which determine the advance of the talus slopes. Whenever they come against steep rock faces, where the process of erosion is likely to be rapid, the talus climbs to a steeper angle because of the larger supply of detritus. It thus tends the sooner to mask the elevation. Where, on the other hand, the rock slopes are gentle, the talus grows less rapidly because of the insufficient supply of debris, and therefore does not advance so rapidly on the barrier. Although the general aspect of these slopes when seen from the distance is that of uniformity as regards their upper margin, closer inspection shows that they vary considerably in that regard, the range in some of the valleys being near a thousand feet of elevation. So far as observed, they are generally highest against the more precipitous faces of the mountains at whose feet they lie.

The measure of the development of the broad valleys will on careful study probably be found to differ much in the several areas of the Cordilleras of this country. There appears on rough inspection to be a distinct increase in the amount of the aggradation as we go southward from the Canadian line, and on the whole a decrease in the amount of it as the region is nearer to the Pacific coast and to the Mississippi valley. In general, the ratio of the infilling seems to be inversely proportionate to the amount of the rainfall that now occurs in that mountain system. In the Montana district the appearance of the taluses, their occasionally eroded surfaces, and what can be seen of the action of torrential rains suggests that the accumulation of detritus is not going on at present with any great speed, if, indeed, it is not replaced by erosion, while in Arizona the amount of debris at present brought down by the flood waters is most noteworthy. Thus in the valley of the Williams fork of the Colorado a flood caused by torrential rains has been observed to cover an area of many thousand acres with debris to the depth of 20 feet or more. On the eastern face of the Cordilleran mountain system in Colorado the aspect of the taluses suggests that they are generally in process of destruction. The same condition is indicated in the belt of country near the Pacific ocean.

The most complete effacement of the original valleys appears to have taken place in the region known as the Mojave desert. Here the detrital slopes have risen to near the tops of the ranges. The most extensive benches and perhaps the broadest of the valleys I have examined are in the basin of Hassayampa river, near Congress junction, Arizona. The least development of the infilling process, still considerable, is the valleys of northern Montana. It has been before noted that along the Pacific coast the amount of debris impounded in the valleys is relatively small.

In the region of the Great basin the phenomena of infilling are more

or less obscured by lake deposits. Such lacustrine conditions, though they may be due to other causes, are likely to be brought about in any of these valleys by the irregular subsidence of their floors under the influence of the loads that are brought on them.

If we were here considering in a general way the effect of any excessive discharge of sediments into a river system in the manner in which it has taken place in the Cordilleran district, we might much extend the subject-matter of this paper. It would be interesting to note that the result of the filling of valleys is to change the effective base line of erosion of all the streams that lead down to them, and that the natural completion of the process is the development of an extensive broad upland with shallow valleys where there was originally a strong mountain topography. In other words, a kind of summit leveling action is then taking the place of the usual baseleveling process. To this condition a large part of the Cordilleran system within the United States is obviously tending.

Although in the absence of close study of the problem these impressions concerning the increase or decrease of the talus slopes can not be considered as more than foundations for inquiry, it may be well to note on what they depend. Where the slopes are continuous and of even surface, with no new-made channels, particularly when they gradually steepen up to the walls of the mountain, there is reason to believe that, while they are subjected to some interstitial decay, they are not subjected to much surface erosion. Where, however, the crest line is sharply irregular, and especially where extensive areas of gently sloping bed rock are exposed, it is a legitimate working hypothesis that the upper edge of the talus has been so far eroded that it has lost a part of its height. Here and there in northern Montana low foothills occur which can not be accounted for by the structure of the rocks, but seem to have been produced by the lessening in the height of the taluses and the consequent dissection of the newly exposed bed rock. A proper determination of this question as to the growth or shrinkage of the taluses under existing conditions will be difficult to make.

While the present average state of growth or decay of the deposits in the broad valleys is not determinable, there appears to be good evidence that there has been at least one period of the past, and that near to our day, when for a time these beds were in process of rapid wasting. This is shown by the general occurrence of many wide and often still deep passages through the slopes where the torrents cross them. These excavations occur in all the broad valleys I have had a chance to examine. It is clear that they have not been formed by the torrents in their existing volume, for they have no fresh scarps, and those of recent date

have usually gentle and completely adjusted slopes. Moreover, in all the many instances I have inspected the torrent is now engaged in constructing a detrital fan within the valley which a while ago it was excavating. Not only are there valleys where the permanent streams intersect the benches, but at many points we find such valleys where there is at present no effective stream at work at any season. These might be taken as the result of torrential rains but for the fact that they all appear to be very ancient. Moreover, they seem to have been excavated by moderate, continuously acting streams and not by a cataclysm. A part of the evidence on this point is afforded by the fact that these ancient *wadys* are in all the regions abounding in alluvial gold, the seat of local placers, the metal being in winnable quantity because it is a concentration from the general mass of the talus deposits. The distribution of this gold in the *wady*, where it occurs in benches of rearranged gravel, shows that these now dry valleys have had an ordinary stream history.

The duration of this last period of more abundant rainfall must have been considerable, for the erosive work done on the taluses was evidently great. The gorges formed by the main torrents were, in many instances, a mile or more wide and from 1 to 300 feet in depth, though they have since been to a great extent refilled during the later now existing stage of accumulation. They generally remain very distinct features. At the present rate of growth of the detrital fans, it would require a geologically long time for the replacement of the debris which was removed from these cross-valleys. It appears likely that this channeling of the valley deposits which is shown where the torrents cross the slopes continued down to the centers of the troughs of the rivers, so that the drainage flowed in canyon-like gorges of considerable depth. Although these canyons cut in the debris are in process of refilling and are sometimes almost occluded, they can often be traced by the slight escarpments which show where their margins lay. Such sections as have been disclosed of the beds which have been laid down in these ancient waterways show relatively fine, worn debris differing in texture from that which makes up the slopes on either side of the river.

So far as the evidence goes, it is to the effect that this period of increased rainfall and consequent reinstitution of erosion in part coincided with the last development of glaciers in this region. It appears to have continued after the retreat of the local ice-streams from the valleys, as is shown by the fact that the morainal fields are incised by channels which are no longer the seat of cutting streams. It may also have somewhat preceded the development of those ice-fields, as is occasionally shown by the semblance of such dead valleys partly covered by drift materials. It is not easy to make observations of value as to this ques-

tion, for the reason that at only a few points have I been able to find morainal deposits lying upon the talus slopes in positions where the history of channels due to increased rainfall can be traced. The best of those lie on the west side of the Jefferson river, between Whitehall and Twin Bridges, Montana. Although the evidence is not as complete as might be desired, it seems to be fairly conclusive as to an increased precipitation before and after the Glacial period, though the amount thereof is not determinable.

The relation of the glacial deposits to the materials which fill the broad valleys clearly establishes the fact that the valleys were in substantially their present state before the advent of the ice-streams. The changes which have taken place in post-Glacial time have been very slight. Certainly not the hundredth part, and probably not the thousandth part, of the detritus borne in from the hills has been laid down since the close of that humid period in which the principal work of excavation was done. If, then, we allow a duration of 100,000 years to have elapsed since the departure of the glaciers from the valleys and the reestablishment of the arid conditions as they now exist—in my opinion, far too short a time—and suppose that the process of infilling has of late been of average rapidity, we are led to conjecture that some million years have elapsed since the work began. As to the time when the change from normal to abnormal stream-work occurred, we have as yet no trustworthy evidence, nor do we know that it took place coincidently in all parts of the region. While by no means conclusive, the evidence in general points to the conclusion that the excavation of these vast basins, as well as the process of their refilling, has been substantially accomplished in the periods since the Cretaceous.

It may be incidentally noted that the effect of the temporary humid climate during the Glacial episode appears to be marked in the conditions of the vegetation of this region. In certain regards the plants, particularly the trees, exhibit a lack of adjustment to the state of the soil such as they now have to meet. The natural way by which plants adapt themselves to arid conditions is by sending tap roots downward to the water level, as in the case of the "beach grass," *Carex arenaria*, which often sends down such roots to the depth of from 10 to 20 feet below the surface. Other instances may be found in the many tap-root trees. It is a noticeable fact these accommodations to arid conditions appear to be generally lacking in the Cordilleran vegetation. It may well be supposed that during the last humid epoch, which may be presumably reckoned as equivalent to the latest Glacial period of the northern hemisphere, this region lost the species which had previously been adapted to dry conditions, and that since the aridity was reestablished

there has not been sufficient time for the differentiation of new species adapted to the environment.

If the presumption just above noted as to the age of the broad valleys be affirmed it will serve to throw much light on the duration of the Cenozoic age. The tendency of geologists has, in my opinion, been to under-reckon this section of time. It is generally computed, from the thickness of the sediments and other evidences, as far less long than the Paleozoic or even the Mesozoic ages. I have elsewhere* undertaken to show that the geological results of that age must have required many million years for their development. If the further study of the Cordilleran valleys bear out the preliminary judgment above set forth we shall have yet stronger reasons for revising our conceptions concerning the duration of the last great geologic age.

Effects of Deposition

There are certain secondary effects arising from the infilling of the broad valleys which deserve attention. In the first place we note that the transfer of a vast body of debris from the mountain ranges to the center of the troughs must naturally have led to the subsidence of the bases on which the weight was imposed and a corresponding rise in the areas whence the materials were deported. If we reckon the average depth of the detrital materials laid down in these valleys at 3,000 feet, then the consequent subsidence should be some large portion of that amount. In all probability the deposits of the greater vales much exceed the amount here assumed. In proportion to the subsidence, but probably somewhat less in amount, there would be a rise in the areas of erosion—that is, the bordering mountain ranges. The axis or neutral point of this movement would naturally lie near the junction of the valley deposits with the high country. Its position would be unstable, as it would tend to become extended farther and farther from the central line of the depression as those deposits encroached upon the steeps. Assuming that this effect arising from the isostatic action occurred—that it in some measure occurred is almost a necessary supposition—there are several interesting consequences that require consideration. In the first place we shall be able thereby to account for the great depth of these valleys without having to suppose that continuously inclined drainage channels cut in the bed rocks still exist. There is, indeed, no reason why the floors of the troughs may not have been borne down for

* Report on the Geology of the Cape Cod District. Ann. Rept. Director U. S. Geol. Survey, 1896–'97, p. 588.

thousands of feet below the level at which the waters which excavated them were of old discharged into the sea or into the greater rivers.

The hypothesis of isostatic movement may serve in part, at least, to explain the often wall-like character of the mountains that face these valleys. As has already been noted, this aspect of these vales is so striking that it demands an explanation. If we assume a continued settling of the floors of the valleys, accompanied by an upward movement of the neighboring ridges, we may well imagine that we would have much faulting about the changing axial line. In other words, each of these valleys would be the seats of more or less considerable step faults, the whole forming a complicated "graben" like basin. There are not lacking instances of a like structure in basins which have been deeply filled with sediments. Thus on the eastern coast of the United States we have in the Richmond basin what seems a similar instance of a valley step faulted under a heavy burden.* The Narragansett basin, in Rhode Island and Massachusetts, is a similar instance of a basin that appears to have been downborne by the weight of sediments imposed upon its floor. It is, indeed, likely that this downbending of loaded troughs is a common feature.

It is to be noted that in the filled basins of the James river and the Narragansett districts of the Atlantic coast, the former of Triassic and the latter of Carboniferous time, we have the same abundant developments of arkose deposits that we find in the broad valleys of the Cordilleras. These facts suggest the hypothesis that the process of occlusion of valleys in the manner indicated in the troughs we are considering may be sufficiently common to be regarded as of general importance. The fact that in the eastern basins there are occasional coalbeds in certain parts of the section may mean no more than the temporary occurrence of humid epochs, such as that which has just passed away in the western part of the country.

It is evident that in case it should be found that deposits of the broad valleys have in a way determined the development of the orogenic movements of the region in which they lie, very interesting light would thereby be thrown on the history of the mountain-building in the Cordilleran and other regions of like conditions. At present, however, the value of the hypothesis is not proved, so that it does not merit further discussion.

There is a peculiar feature in the recent volcanic activity of the Rocky mountains of which we may possibly find an explanation through the action of the valley deposits. This is the occurrence of eruptions at various points at a time when the sites of these outbreaks were remote

*See Ann. Rept. Director U. S. Geol. Survey, 1897-'98, p. 401.

from the rea. It is a well known fact that no such explosions have been noted in the historic period at a greater distance than about 250 miles from the ocean; yet many of the eruptions in the Cordilleran district which have recently occurred are several times as far from the coast. The only apparent reason for the limitation of volcanoes to the sea-floors or to the margins of the lands is that the development of the tension, principally of steam, that brings about eruptions is caused by the rise of temperature in rocks due to the non-conducting effect of strata which have been laid down on the sea-floors. Accepting this explanation, it appears not unlikely that the outbreaks which have taken place in the region we are considering may have been caused by the great deposits which have been accumulated over the wide area of the broad valleys. It is true that the rise in temperature would not in general exceed one degree Fahrenheit for each 50 feet of beds laid down, and that a depth of 10,000 feet would probably effect no more increase in the basement of the section than 200 degrees Fahrenheit; yet such a gain in heat might at a depth in the crust when the tensions were already near the critical part of an explosion be efficient in bringing it about. Moreover, as is indicated by the hot springs in this region, there are evidently many large areas where the temperatures at no great depth are high, a condition due perhaps to ancient volcanic pipes or great dikes or sheets of lava which are still very hot. In case these were deeply covered with sediments the rate of rise of the isogeothermal planes would be much more rapid than would ordinary conditions, and an explosive tension would be more readily attained.

It may be asked why the eruptions from the interior districts of the Cordilleras have apparently now ceased, while they were evidently of frequent occurrence in the later Tertiary and perhaps in the early Cretaceous periods. The answer may be found in the fact that the process of deposition in the broad valleys was evidently arrested during the humid period, of which the local glaciation of the region was an incident, and that for some time and in a considerable measure it was replaced by erosion. The further deposition now going on has evidently not been sufficient to restore to these valleys what was removed during that time of more abundant rainfall. The only sufficient verification of the hypothesis that these inland volcanoes owed their origin to local deposition will be had in an examination of other countries where like deeply filled broad valleys exist. I have essayed this through records, but these are so imperfect that they have not proved serviceable.

Some of the apparently modern eruptions of the Cordilleran region appear to negative this hypothesis, as, for instance, those which have occurred in the Colorado canyon. I have not been able to examine

these seeming exceptions sufficiently to determine whether they render the view above suggested untenable.

Exceptional Valleys

It has been incidentally noted that in certain parts of the Cordilleras valleys occur which clearly indicate a different adjustment of the conditions of erosion from those long prevailing in the characteristic refilled broad valleys. So far as I have been able to examine these exceptions they appear to be accounted for by peculiarities of situation or by exceptional movements of the underlying earth. The diminution in the amount of infilling after the periods of great erosion on the Pacific coast is explicable from the fact that these valleys near the ocean have never had their streams so far reduced in flow as to bring about any large amount of aggradation. There are, however, two districts where the process of infilling is absent or noticeably less than might be expected if the hypotheses here advanced to account for the broad valleys were true. These are the sections traversed by the canyon of the Colorado and that on the eastern face of the Cordilleras from central New Mexico to the Canadian line. The reasons for these exceptions may perhaps be found in certain geographical accidents that are noted below.

As for the Colorado river, it is well known that, while it traverses one of the most arid portions of the Cordilleran region, it derives its water from the snows of the high mountains on the eastern side of the Rocky mountains, where for ages the precipitation must have been considerable. Cutting as it does through a region which clearly has long been characterized by a very scanty rainfall and where there has been an extensive upward movement of the rocks, it has formed and kept open a deep valley. Although the sides of this trench have been much intersected by tributaries, the amount of debris which they have brought down has not been greater than the vigorous river has been able to take away. The result is a valley in which the stream has been able in the main to retain its place on the bed rock. As these conditions of the Colorado river are rather exceptional, and as they appear to account for the lack of aggradation we find there, we may therefore reasonably conclude that the features of this valley do not militate against the hypothesis.

As elsewhere noted, the eastern face of the Cordilleran district affords evidence that goes to show a recent augmentation of rainfall beyond any increase that is indicated in the central region. This is most evident in the southern portion of this district, as in southern Colorado and New Mexico. In that area we have fairly broad valleys which often exhibit the form of the bed rock cut, which has been described as existing be-

neath the alluvial deposits of the Silver Bow river at Butte, Montana. They have wide bottoms, declining gently from the base of the bordering ranges to near the center of the trough, and then a sharp canyon-like gorge descending to the ancient level of the stream. A fair though small example of these structures is seen in canyon Diablo, on the Santa Fé railway. The simplest explanation of these valleys would be to suppose that after they were broadened out in adjustment to one baselevel of erosion the region in which they lie had been elevated or tilted so as to increase the cutting power of the streams. There are, however, several reasons why this view is not satisfactory. In the first place, as just above noted, the shape of these vales is identical with what we find in those of the more arid district which has been filled with debris. In the second place, these troughs lie too far above the sea to have had the regimen of their streams altered by any such change in its level as has recently occurred. The central canyon is by no means continuous down to the coast line, as should be the case if its existence was due to recently augmented erosion brought about by a change of level. As for the suggestion that there has been an increase of erosion due to tilting, evidence to show such movement is quite lacking; there is no such contrast in the conditions of streams flowing in diverse directions as normally, indeed necessarily, marks a drainage system which has been thus perturbed.

Any alteration of the slopes of this region sufficient to have produced the reexcavation of these valleys would be indicated by a general disturbance of drainage such as has evidently not occurred.

Along the eastern face of the Rocky mountains there are several features which deserve notice, for the reason that they appear to throw some doubt upon the hypothesis that the long continuance of an arid climate will account for the refilling of valleys excavated during humid periods. First of these is the deep canyon valley of the upper Arkansas river. This gorge is on some accounts more puzzling than that of the Colorado, for the reason that while the upper part of the trough is of normal width and has been extensively refilled, the canyon section is relatively narrower than almost any other formed by the Cordilleran streams. I have been unable to determine the reason for this peculiar feature. It may be due to some recent uplifting of the section in which the canyon lies, or possibly, though not probably, to a difference in the rate of decay of the rock in the different parts of the valley. It should be noted that this stream, like the Colorado, is fed from the melting snows of a high country where the rainfall is and doubtless has long been considerable. The fact that the valley above the gorge was the seat of extensive glaciation during the last ice epoch clearly indicates that the annual precipitation has recently been much greater than it is at present.

The frequent occurrence of foothills at the base of the main ranges, both on the eastern face and in the valleys of this section of the Cordilleras, is noteworthy. Here, as elsewhere, these low ridges have noticeably accordant heights; they are, moreover, much less dissected than are the mountain at whose feet they lie. Wherever these foothills are well developed the talus slopes are inconspicuous or wanting. If the view previously expressed, to the effect that foothills of this type result from the exposure of a portion of the gently sloping bed rock of a valley which took its first shape while the process of refilling was going on, then the process of baring and dissecting must have been a concomitant of an increased rainfall which has served to destroy the ancient talus slopes or benches. In other words, we have to suppose that an arid period, during which extensive taluses were built, was followed by a humid period, in which they were to a great extent swept away.

Possible Cause of increased Rainfall in eastern Cordilleras

At first sight it may seem that the last Glacial period, with its increased precipitation, could sufficiently account for the augmented rainfall which the features just above noted appear to demand for their explanation; but it is probable that the increase in erosive action in this eastern section of the Cordilleras is much more ancient than the ice-time. Although the dissection of the upper part of the rock slope is often of the canyon type, the incisions are deep and apparently must have required far more time than elapsed since the beginning of that humid period. In view of the facts, I have been led to a hypothesis as to the cause of this ancient temporary increase of rainfall and of the aridity which preceded it. This view I shall now set forth.

It is eminently probable that the source of the larger part of the rainfall that comes to the drainage basin of the Mississippi valley, including the eastern portion of the Cordilleras, is to be found in the basin of the gulf of Mexico and the Caribbean sea. Depending on the evaporation from this basin as the source of precipitation, we may reasonably suppose that any great variations in the area of these seas would be attended by changes of rainfall which might, if the alterations were great enough, range through a wide scale. Although we can not as yet clearly trace the alterations of the Caribbean group of seas in the later geological periods, we know enough to be sure that these have been great. Developing mainly about the eastern and western mountain systems, this continent has, since the Paleozoic age, had a broad, low interval between the Appalachian and Cordilleran high ground—a region so little elevated above the average level of the ocean that it has in many alternations been dry land and shallow sea. Still further, in southern Louisiana, where

there is at present an annual rainfall of about 100 inches, there exist very extensive deposits of rock-salt beds, which indicate an arid climate, with a precipitation of probably less than 10 inches, and a very dry air. Although the age of these beds is not determined, it is, on the whole, likely that they are of Mesozoic age. These facts, while they do not suffice to correlate any particular climatal condition in the eastern face of the Rocky mountains with a particular accident in the form of the gulf of Mexico, clearly indicate the existence of actions sufficient to account for a wide range in the precipitation in that part of the Cordilleras. If it were necessary further to show that the eastern border of the Cordilleras had been subjected to one or more humid periods before the last Glacial epoch, the evidence could be adduced from the conditions of the valleys of the rivers which drain from that district toward the Mississippi. These valleys generally indicate the existence of a greater flow, and this at a time anterior to the accumulation of the glacial drift.

Conclusions

The foregoing considerations lead to the conclusion that the valleys of the eastern face of the Cordilleras were in most, if not all, cases greatly affected by a long-continued arid climate, which at some time probably in the Tertiaries was interrupted by one or more continuously humid periods, with a return in the present epoch to dry conditions. During the Tertiary periods, when aridity prevailed, the originally deep and rather narrow valleys probably were filled with debris and widened under the conditions of a constantly rising baselevel formed by the thickening deposit, the conditions of this action being the same as those traced in the interior valleys of the Cordilleran field. At the same time like accumulations of detritus formed on the eastern border of the mountains—that which faces the great plains. In later times there came a greater measure of rainfall, and, as a consequence, the removal of a large part of the filling of these eastern valleys, as well as the greater portion of the talus deposits on that border of the mountains. In this period the upper part of the bed-rock slopes of the valleys were bared and worn into foothills.

At present the conditions of the eastern section of the Cordilleras indicate a recent return to the arid climate which has for ages been normal in that area. The taluses are evidently again in process of increase, vigorous erosion being limited to the higher levels, where the steepness of the torrent beds enable their scanty waters to sweep along the debris which comes to their beds. Unless the gulf of Mexico should again be brought over a considerable part of the southern lowlands, there seems to be no reason to expect that there will be any increase of rainfall in this area.

FIGURE 1.—DEVONIAN SHALES AND SANDSTONES OF THE KNOYDART FORMATION

McArras brook, Antigonish county, Nova Scotia

FIGURE 2.—SILURIAN STRATA, MOYDART FORMATION

Arisaig coast between McPhersons brook and Moydart point, Antigonish county, Nova Scotia

KNOYDART AND MOYDART FORMATIONS OF NOVA SCOTIA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 301-312, PL. 26 AUGUST 16, 1901

KNOYDART FORMATION OF NOVA SCOTIA*

BY HENRY M. AMI

(Read before the Society December 28, 1900)

CONTENTS

INTRODUCTION

While engaged in making a paleontological survey of the rock formations of the Upper Paleozoic in Nova Scotia, and also studying material placed at his disposal from previous collections in the Geological Survey Department, the writer has discovered what appears to be sufficient evidence for the determination of the geological horizon of a series of strata which occur in the western corner of Antigonish county, extend into the adjacent county of Pictou, Nova Scotia, and measure probably not less than 1,000 feet in its greatest development. One of the best natural sections where this series may be examined and studied to advantage occurs in the valley of erosion through which flows McArras brook. A measured section recently made by Mr Hugh Fletcher, of the Geological Survey of Canada, and cited below, gives a total thickness of 684 feet. The strata in question are placed in the Lower or Eo-Devonian, inasmuch as they contain fossil remains characteristic of the typical "Old Red Sandstone" of Europe.

TYPICAL AREA UNDER DISCUSSION

On sheet-map number 34 of the series of geological maps of Nova Scotia, issued by the Geological Survey of Canada in 1893, there is rep-

*Published by permission of the Director of the Geological Survey of Canada.

resented a lozenge-shaped area of so-called Upper Devonian strata adjacent to the Silurian of the Arisaig Coast region and extending from the headwaters of Arisaig brook on the east to those of Baileys brook on the west, and from "The Hollow," or "Bruin's Highway," on the south, to the line of contact and overlap of Carboniferous strata to the north and west.

This area is described as "Upper Devonian" on page 69 P of the "Annual Report" of the Geological Survey of Canada for 1886. Here the first mention of the occurrence of organic remains found in this series is given in what appears to be the lowest portion of the series. These include "plants, fish teeth, and Protichnites." A number of small streams cross this area of Devonian rocks and afford many interesting outcrops, of which one of the two photo-sections reproduced in the plate opposite this page, occurs near the bridge over McArras brook, along the shore or postroad from Merigomnish to Arisaig and cape George. These streams include the headwaters of McAdam brook, Joseph McDonald brook, Stonehouse brook, McArras brook, Knoydart* brook (giving the name to the formation discussed), Vamey brook, and of one of the southeastern branches of Baileys brook.

Contact of Silurian and Devonian Strata

The line of contact between this area and the adjacent Silurian appears to mark an unconformity, the precise amount and significance of which has not yet been fully determined. According to the dips and strikes given by Mr Hugh Fletcher and Mr J. A. Robert on the map just cited, it would follow that, on the whole, the general trend and behavior of the strata referred to the Silurian and Devonian systems are fairly uniform and generally identical, both having evidently been subjected to the same physical forces and disturbing agencies since they were deposited (see plate 26, figures 1 and 2).

The actual dips of the Devonian strata vary from 16 degrees to 80 degrees, and those of the Silurian from 7 degrees to 70 degrees, with local variations in both. The number of post-Silurian and post-Devonian eruptive masses of amygdaloidal trap present in the vicinity have done much to disturb the rocks of the two sedimentary series, not to speak of the older and the newer sedimentaries of the district (see map, figure 1).

Classification and Views of Various Writers

Touching the McArras brook area in question, the conclusion cited below was reached by Mr Hugh Fletcher by correlating the same with

* Pronounced Krodiart.

FIGURE 1.—*Geological Map of Portions of Pictou and Antigonish Counties, Nova Scotia.*
Indicating the relations of the Knoydart formation (Old Red Sandstone) and associated formations

the New Brunswick equivalents in his "Report of geological surveys and explorations in the counties of Guysborough, Antigonish, Pictou, Colchester, and Halifax from 1882 to 1886."

In this Annual Report, 1886, new series, volume ii, under the head of "F. Devonian," on page 49 P, Mr Fletcher describes three distinct groups of Devonian strata corresponding closely with those of New Brunswick, and gives the following table of equivalencies:

New Brunswick	*Nova Scotia*
3. Mispeck group.	3. Upper Red slate and sandstone group.
2. Dadoxylon sandstone and Cordaite shale.	2. Middle gray sandstone and slate group.
1. Bloomsbury conglomerate.	1. Lower Conglomerate group.

After giving the distribution of the above in Nova Scotia in general, the first reference to the age of the McArras Brook strata is then made on page 49 P, which reads as follows: "The upper rocks" (*i. e.*, the Upper Red slate and sandstone group) "are found again near Union Railway station, and also at McArras brook."

On page 67 P Mr Fletcher quotes Dr Honeyman's * views on the age of these rocks: "They are certainly not Lower Helderberg, and may therefore be Devonian;" and on page 68 P the same writer quotes Sir William Dawson,† in which he regards them as "pre-Carboniferous, although not separated from the Silurian."

Mr Fletcher describes the strata on McArras brook as follows:

"Good exposures are also cut by McArras brook behind the mass of amygdaloid at the shore, consisting of red, flinty, micaceous, jointed sandstone and slate, often concretionary, interstratified with greenish thick bedded and flaggy sandstone, containing traces of carbonate of copper and iron pyrites, the brook being rocky up to the shore road.

"From the latter a collection of fossils was made by Mr Weston, comprising fragments of plants and fish teeth, not certainly determinable, together with certain interesting footprints, *Protichnites carbonarius*." ‡

Discovery of Fossils and their Interpretation

Up to 1886 but little had been done with a view to determining the exact geological horizon to which this Devonian area belonged, the area in question having been generally dismissed with the statement that they were certainly non-Silurian. In that year Mr T. C. Weston and

* Trans. Nova Scotian Inst. Sci., vol. 3, pp. 13, 188.

† Acadian Geology, p. 516, line 4, and Supplement to the same, p. 49.

‡ Those tracks have since been described by the writer under the name *Ichthyoidichnites acadiensis* in a paper read before the Nova Scotian Institute of Science in May, 1901.

Mr J. A. Robert carried on a successful paleontological survey of the Silurian as well as of the Devonian rocks of the region. The Silurian fossils obtained were submitted to a preliminary examination by the writer in that year, and a list of some 160 species of organic remains was recorded in the Silurian formations of the Arisaig coast, referable to the various subdivisions A, B, B′, C, D, and D′ of Dr D. Honeyman, as adopted by Mr Fletcher, exclusive of the species recorded by J. W. Salter, J. W. Dawson, James Hall, E. Billings, and Dr H. Honeyman.

From the Devonian strata Messrs Weston and Robert obtained what appeared to be series of obscure fishes, together with tracks and trails of some organism. These were not determined, however, until the writer undertook to submit the fish material to Mr A. Smith-Woodward, of the British Museum. The result of the study of the fish fauna has led the writer to conclude that instead of Upper Devonian strata in the McArras Brook, Upper Knoydart Brook, and Upper Vamey Brook exposures, there occurs a series of strata of lowermost Devonian age, equivalent to the Lower Old Red sandstone of Britain or Cornstone of England. The highest fossiliferous strata of the Silurian series adjacent are so remarkably similar in their lithologic and paleontologic or biologic characters to the facies of the Silurian of western Europe—especially to the Silurian of the Ludlow type in Herefordshire, England—as to warrant a close relationship to be instituted with the European equivalents: quite distinct from the Silurian succession as known in the Gaspé peninsula, in the valley of the Saint Lawrence, on the island of Anticosti, and in the state of New York or the province of Ontario to the south and west as defined and described by Vanuxem, Hall, Logan, Billings, and other geologists.

This Lower Devonian area is bounded on the east by the highest member of the Silurian examined, the Stonehouse formation, and on the south by a range of hills which has been assigned to the Cambro-Silurian (Ordovician) by Mr Fletcher.* From this series, however, no organic remains or definite paleontologic evidence of any value have as yet been obtained upon which might be determined the precise position of this older series in the Paleozoic succession. To the north and west of this Devonian area are seen newer measures referable to three distinct horizons of the Carboniferous system as developed in this portion of Nova Scotia. These include—

(*a*) The so-called "Carboniferous Conglomerate" formation described in the above report.† This series is presumably equivalent to the Bonaventure formation of Gaspé, and is doubtfully referred to it here.

(*b*) The "Carboniferous Limestone" series with its marls, sandstones,

* Annual Report of the Geological Survey of Canada for 1886, pp. 17 P and 99 P.

† Loc. cit., supra, pp. 71 P, 85 P, and 124 P, and on page 173 P of the Annual Report for 1890–'91.

and marine limestones and gypsum, designated (in part at least) by the writer, as the Hopewell formation.*

(c) The so-called "Millstone Grit" series, for the most part very flat lying and undisturbed, showing that the physical disturbances and agencies to which the Silurian and Devonian strata have been subjected which have dislocated and tilted their strata had disappeared previous to the time when these Carboniferous grits were laid down. This so-called "Millstone Grit" series, which is very doubtfully the equivalent of the true "Millstone grit" of England, was designated by the writer as the *Westville* formation, on page 178 of the paper cited above, in order to separate it from other formations in the district.

Fletcher's Section of the Knoydart Formation along McArras Brook

In 1897 Mr Fletcher made a careful remeasurement of the red marls, sandstones, shales, and calcareous bands holding fish remains along the valley of McArras brook, a copy of which was kindly furnished me by him with the sanction of Doctor Dawson, director of the Geological Survey. In order to give the reader more detailed information on the succession of the strata in this bit of the "Old Red Sandstone" his valuable section has been incorporated in this paper.

From the mass of trap near the mouth of McArras brook the following is the section in ascending order:

	Feet.	Inches
Amygdaloidal trap, probably Lower Carboniferous, as described in Report P for 1886.		
Measures concealed. On the left bank of the brook trap is in the cliff, while on the right bank there are indications of red stratified Devonian rocks	30	0
1. Red, argillaceous shale, more or less slaty, with coherent underclay full of rootlets, dip north 230 degrees angle 32 degrees (magnetic)	3	0
2. Red, argillaceous, slaty rock, not well seen	4	0
3. Red, broken, argillaceous shale, with greenish and gray blotches.	6	0
4. Red shale, nearly all concealed	6	0
5. Red, very coherent, concretionary, calcareous rock at the mouth of a little brook from the eastward	1	6
6. Red, argillaceous shale	7	6
7. More coherent, flaggy rocks, which may be called sandstone	1	0
8. Red, argillaceous shale	8	0
9. Red, coherent, somewhat sandy flags, in two layers	3	0
10. Red, argillaceous shale, in part blotched with green	46	0

* Proc. and Trans. Nova Scotian Inst. Sci., vol. 10, pt. 2, Halifax, 1900, p. 177.

	Feet.	Inches
11. Greenish and reddish, coherent, micaceous sandstone and flags, with fossils (no. 1)	4	0
12. Red, argillaceous shale, with coherent layers	22	0
13. Red, somewhat coherent, massive, argillaceous rock	6	0
14. Red, coherent flags, containing fish remains	11	6
15. Red, argillaceous shale	5	0
16. Greenish, calcareous flags, from which Doctor Ami collected many fossil fish remains in 1897. The upper part contains broken carbonized plants, fish, etcetera (no. 2)	2	0
17. Red and green, somewhat massive, mottled, calcareous rocks, with nodular, rounded, and oval spots and fish remains, dip 230 degrees angle 29 degrees on fine long faces	7	0
18. Red, argillaceous shale, with layers of more coherent concretionary flags	5	0
19. Red, micaceous flags	1	6
20. Red, somewhat crumbly, argillaceeus shale, forming fine ledges in the brook	2	0
21. Red, argillaceous shale, with layers of fine, more coherent flags.	14	6
22. Greenish, flinty, argillaceous, and siliceous flags, micaceous and sometimes spotted with red, containing much carbonaceous matter and cut by veins of quartz (no. 3)	3	0
23. Greenish, coherent, massive, fine sandstone in two layers	4	0
24. Red and greenish mottled shale, in regular layers, more massive toward the top, for the most part red	8	0
25. Reddish, coherent flags and argillaceous shale	32	0
26. Red, crumbly, argillaceous shale, not well seen	11	0
27. Red, crumbly, argillaceous shale, with harder bands, not well seen	10	0
28. Red, argillaceous shale, with flaggy layers	17	0
29. Red, argillaceous shale, not well seen	25	0
30. Red, coherent, thick bedded sandstone, in two layers, at a small waterfall	6	0
31. Red, coherent, argillaceous shale, with green layers and blotches.	5	0
32. Measures not well seen, but evidently chiefly red	6	0
33. Greenish, argillaceous shale at the mouth of a little brook from the westward (no. 4); from this the seeds and plants were obtained by Doctor Ami in 1896. One coarse, rusty layer is full of pyrites and plant remains	2	6
34. Measures concealed, probably greenish shales cut by quartz veins and containing plants	3	0
35. Greenish quartzite or fine sandstone, over which the little brook from the westward falls into the main stream at water level..	3	0
36. Gray and greenish and red coherent argillaceous rock in three layers	3	0
37. Red, argillaceous shale, with coherent layers. The top comes to the foot of the falls in a gorge from which Mr Weston is supposed to have obtained his fish remains (no. 5)	12	0
38. Red, coherent, argillaceous shale, forming a little fall	15	0

	Feet.	Inches
39. Red, coherent shales, forming a higher fall.	14	0
40. Red, argillaceous shale, containing greenish blotches, harder layers, and small nodules; to the water level of the lower side of the culvert at the shore side	31	0
41. Red, argillaceous rock, with green layers and blotches, in cliffs at the road, dipping 235 degrees angle 32 degrees	30	0
42. Red and green mottled, argillaceous shale, principally red	15	0
43. More coherent, red, siliceous and argillaceous rock, with a few fish remains	10	0
44. Greenish and mottled lenticular limestone from which Doctor Ami obtained the fish remains *Pteraspis*, etcetera, first sent to Doctor Woodward (no. 6)	0	6
45. Red, argillaceous and siliceous rock with green bands and blotches	20	0
46. Reddish, altered rock at the level of the road under the schoolhouse, not well seen	20	0
47. Greenish, argillaceous flags and shales (no. 7)	4	0
48. Red, argillaceous shale	3	0
49. Red and greenish sandstone in two layers	4	0
50. Red, argillaceous shales, with layers of more coherent rock, some of which contain rootlets	17	0
51. Measures concealed	13	6
52. Bright red, soft, argillaceous shale; to the first bridge where the brook crosses to the eastward	4	0
53. Red, argillaceous shale, with a few more coherent layers	31	0
54. Greenish, somewhat massive, argillaceous and arenaceous rock (no. 8); at the second bridge where the brook runs to the westward. The dip now changed to 80 degrees, and this layer is concealed for some distance, but again appears to return to the road farther south. Assuming that this is the case, the section is continued beyond as follows	11	0
55. Red, argillaceous shale, with coherent layers	18	0
56. Greenish and dark-gray crumbly, argillaceous rock	2	0
57. Greenish and gray, argillaceous rock, the upper part greatly altered	4	0
58. Trap	4	0
59. Red, argillaceous shale, greatly altered	6	0
60. Measures concealed dip 250 degrees angle 23 degrees; to a little brook from the eastward	5	0
61. Red, argillaceous shale and thin flags, in which fish remains were found (no. 9)	14	0
62. Red, argillaceous shale and flags	43	0
63. Trap, thickness undefined, perhaps	120	0
This trap begins about 550 yards above the main road. In the brook west of the road there is a green flinty shale which yielded no fossils.		
Total thickness of the stratified rocks in the section	683	3

Mr Fletcher adds:

"This section is only approximate. It represents only a small portion of measures, apparently as thick as at Union; seen also in Knoydart brook and other streams of the vicinity. It is not supposed that either the base or the summit of the series is here given."

Name and Fauna of the Knoydart Formation.

The name "Knoydart formation" is proposed for the series of strata of which the 684 feet recorded above constitute a characteristic section holding a typical "Old Red Sandstone" fauna. This name is given in order to be able to better designate the strata in question and separate them from other Paleozoic formations in that portion of eastern Canada where the sedimentation has a wonderfully close resemblance to European types. This striking resemblance to the European succession is a feature which has been pointed out by Sir William Dawson, Salter, Billings, Honeyman, and other writers.

The following species of fossils obtained from the above strata are provisionally recorded as characteristic of the Knoydart formation. These and other forms will, no doubt, sooner or later be found in other parts of Antigonish, in Pictou, and in other counties of eastern Canada along the Atlantic border of the continent. The fossil ostracoderms, which constitute a very primitive and early type of fishes, were identified by our friend Doctor A. Smith-Woodward, of the British Museum, and to him is due the credit of identifying the fish fauna and indicating the precise geological horizon to which to refer the beds, while the remains of Pterygotus were submitted to and identified by Doctor Henry Woodward when Keeper of the British Museum.

1. *Pterygotus* sp.
2. *Onchus murchisoni* Agassiz.
3. *Pteraspis* sp. cf. *Pteraspis crouchii*.
4. *Psammosteus* sp. cf. *Psammosteus anglicus* Traquair.
5. *Cephalaspis* sp. Probably a new species.
6. *Ichthyoidichnites acadiensis* nobis. Impressions made by a pair of sharp-pointed organs or spines, probably those of a fish.

The specimens are for the most part imperfectly preserved in a hard, compact, fine grained, and brecciated volcanic ash-bed, and are consequently difficult to identify and obtain.

Barlow's Description of Volcanic Ash Rock

With a view of ascertaining the exact nature of the rock materials in which the pteraspidians were preserved, microscopical sections were pre-

pared and submitted to Doctor A. E. Barlow, of the Geological Survey of Canada. He kindly undertook to describe these, and gave the following interesting note regarding the tufaceous or volcanic origin of locality number 6, and number 44 of Mr Hugh Fletcher's section:

"The rock of McArras brook is a dark gray to greenish gray thinly bedded graywacke, weathering yellowish or brownish, owing to the decomposition of the iron ore. It is composed for the most part of angular, subangular, and rounded grains of quartz and feldspar embedded in a matrix of the same materials in a finer state of division. Calcite is present, and in some sections is a rather abundant component of the groundmass. Chlorite in occasional plates and small scales of sericite is also present. The rock is probably of tufaceous origin. Small seams or veins of calcite and quartz frequently traverse the rock."

Paleontologic Notes and Faunal Relations

In reporting upon the fish fauna from this formation, Doctor Smith-Woodward writes: "The McArras Brook specimens represent the base of the Lower Old Red sandstone of Britain."

The presence of pteraspidians, cephalaspidians, and acanthodians, as well as Pterygotus, as determined by Mr A. Smith-Woodward and Doctor Henry Woodward, of the British Museum, would seem to indicate clearly the presence of a fauna precisely similar in facies to that of the Hereford beds, referable to the Lower Devonian (Old Red Sandstone) or Cornstone.

The Pteraspis found in the tufaceous rock in the series of strata is one which Mr Woodward refers to as very closely allied to, if not actually identical with, *P. crouchii* of the English rocks.

The horizon indicated is low down in the Devonian and not far from the summit of the Silurian. From the nature of the sediments, their composition, origin and general characters they appear to be much more closely related to European Devonian or Old Red Sandstone strata than to the usual type of North American Devonian, such as are met with in synchronous western epi-continental formations.

Sir Archibald Geikie* points out the occurrence in Nova Scotia and New Brunswick of the two divergent Devonian and Old Red Sandstone types of Europe, but does not attempt to give any of the subdivisions of the rocks of this system nor any of the fossil organic remains found in them. The fauna of the Arbroath flags or Lower Old Red Sandstone of Murchison is remarkably similar to that of the Knoydart formation.

In his "Geology, Chemical, Physical, and Stratigraphical," Sir Joseph Prestwich † makes the following statement regarding the "Old Red

* Text Book of Geology, 1895 edition, book vi, part 2, sec. 3, chap. 2, par. 2, p. 803.
† Chapter vi, "The Devonian system: 'The Old Red Sandstone,' p. 82."

Sandstone" of Herefordshire, which enables geologists to correlate the strata with a marked degree of proximity to certainty:

"The Old Red Sandstone" of Herefordshire was long thought to be non-fossiliferous, a few fragmentary specimens only having been found when in the railway cuttings near Ledbury, the Rev. W. S. Symmonds (see Quart. Journ. Geol. Soc., vol. 16, p. 193, and vol. 17, p. 152) discovered in the lowest beds (the Ledbury shales) of that formation remains of Pterygotus, Onchus Pteraspis, and Cephalapsis, together with large numbers of the head shields of Auchenaspis."

It is impossible to read over the association of forms in the strata near Ledbury, in Herefordshire, without recognizing in them a fauna and horizon similar to that met with at McArras brook, in Antigonish county, Nova Scotia.

In 1843 Doctor Abraham Gesner described* an "Old Red Sandstone" or Devonian group, which he recognized above Silurian beds . . . in several parts of the province, . . . consisting of . . . "a bright red micaceous sandstone or conglomerate, accompanied by thin beds of red shale and marly clay, and in some places containing seams of fibrous gypsum." He adds: "Hitherto no organic remains have been found in it." He recognizes it at Advocate harbor and on the Moose river, where it is "seen lying unconformably beneath the Coal Measures."

Mr Fletcher classes the rocks of Advocate harbor as Devonian, so that the "Old Red Sandstone or Devonian group" of Gesner must therefore be classed with the rocks of Union and Riversdale, which, from the fauna and flora found in them, are referable to the Carboniferous system, and from their position in the stratigraphic succession may be referable to the Meso-Carboniferous. The gypsum-bearing strata of Gesner are likewise also Carboniferous and not Devonian.

In November, 1899, in a communication on a number of fossil fishes sent him by the writer from various localities in Nova Scotia, in which the geological horizon and precise affinities of the species sent were doubtful, Mr Smith-Woodward, the eminent authority on Paleozoic fishes, gives the following notes on the specimens from McArras brook, adding that they had been submitted by him to Doctor R. Traquair, of Edinburgh:

"The specimens from McArras brook are extremely interesting, and represent the base of the Lower Old Red Sandstone of Britain. The pteraspidian remains are sufficient to prove that they belong to the genus *Pteraspis*. Both dorsal and ventral shields are so much like those of *P. crouchii* that if these Nova Scotian fossils had been found in western England we should have referred them to the latter species. Perhaps the rostral plate may prove to distinguish your form when it

* Proc. Geol. Soc. London, 1843, vol. 4, part 1, no. 65, p. 187.

is completely known. One piece of dorsal shield in counterpart shows the impression of the supposed branchial pouches on one side.

"The pointed fragments in the collection may be *Cephalaspidian cornua*, but are uncertain. There is also present the typical *Onchus Murchisoni*.

"Most interesting is one small fragment of *Psammosteus*, with ornament identical with that of *P. anglicus*.* In this fossil the chambers of the middle layer are larger than in our unique plate.

"On the whole, I should place the McArras Brook beds on the same horizon as the Lower Old Red Sandstones-Cornstones of the Hereford district of England above the passage beds."

Conclusions

It may thus be safely concluded, with the evidence at hand, together with the learned opinion of Messrs Arthur Smith-Woodward and R. H. Traquair, that we have in Nova Scotia an area of Lower Devonian rocks which represent well in America the lower portion of the Old Red Sandstone of Europe. This latter series of strata, together with the Devonian rocks proper, Sir Roderick Murchison held to be the result of "different geographical conditions of the same period." The same statement may be uttered with all truth in North America. From the character of the strata, it is evident that lacustrine deposits were laid and shallow-water conditions prevailed throughout the Knoydart area in Eo-Devonian times, and a lake similar to lake Orcadie, lake Caledonia, lake of Lorne, the Welsh lake, etcetera, of Great Britain, so graphically described by Sir Archibald Geikie, existed in Canada, to which the name *lake Pictou* might appropriately be given.

It may here be remarked that the Knoydart formation of Nova Scotia finds a near equivalent in the Eo-Devonian strata of the Campbellton formation in the Baie des Chaleurs region. To the lake in which *Coccosteus* (*Phlyctænaspis*), *Cephalaspis*, *Protodus*, *Ctenacanthus*, *Acanthodes*, *Cyclora*, etcetera, once flourished in the Bay des Chaleurs region, the name "lake Chaleur" is suggested.

It is an interesting fact to note that much contemporaneous volcanic ash materials constitute the deposits of both these ancient Paleozoic lake basins—"lake Pictou" and "lake Chaleur."

* See Traquair, Ann. Mag. Nat. Hist., ser. 7, vol. ii, 1898, p. 67, pl. 1, figs. 1, 2.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 313-342, PLS. 27-28 AUGUST 31, 1901

KEWEENAWAN AREA OF EASTERN MINNESOTA

BY C. W. HALL

(Presented before the Society December 30, 1899, and December 28, 1900)

CONTENTS

Topography and Physiography

THE AREA DEFINED

In eastern Minnesota south of lake Superior the area known to be underlaid by the Keweenawan series comprises about 900 square miles. It borders the state of Wisconsin for at least 100 miles, and lies almost wholly within the valley of the Saint Croix river.

The northern limit of the district is near latitude 46° 25′, at the boundary line between Minnesota and Wisconsin; the southernmost point exposed is in the lower Dalles of the Saint Croix near Franconia (latitude 45° 15′), although the lava flows of the southern exposures stretch beneath the Cambrian formations southward beyond Stillwater. Westward the Keweenawan stops abruptly along a fault line which nowhere passes beyond longitude 16 degrees west of Washington. The total length of the area is nearly 70 miles, and greatest width not more than 30, with an average of 12 to 14 miles.

SURFACE FEATURES

The surface is generally level. In the northern part the watershed separating the Lake Superior drainage basin from that of the Saint Croix is a morainic tract, which slopes southward into a well timbered and generally level belt of country. Its prominent features are due to glaciation, followed by post-Glacial river erosion. In pre-Glacial time the Cambrian sandstones undoubtedly covered this entire region, from which they are now mostly eroded. The distribution of the sandstone debris has affected in no small degree the agricultural possibilities of much of the district by the formation of extended sand plains, which locally support a partially xerophytic vegetation, the Jack pine, oaks, and underbrush being especially characteristic of the more sandy belts.

RIVER EROSION

The visible erosion features of this part of Minnesota and adjacent parts of Wisconsin are chiefly Glacial and post-Glacial. Exceptional is the immediate gorge of the Saint Croix river through a part of its course, an exception soon to be considered. The tributary streams form their sources in the north to the level of the Saint Croix river at Franconia,

where the southernmost Keweenawan rocks of Minnesota disappear beneath the Cambrian sandstones, descend from an altitude of 1,200 feet above the sea to 700 feet. The fall of 500 feet is sufficient to afford considerable erosive power, yet, owing to the newness of the district physiographically, very little rock-cutting has been done beyond the removal of the glacial drift along the channels of the streams.

The Kettle river in its course from Kettle River station to its confluence with the Saint Croix flows less than 30 miles and falls 220 feet. While it has cut into the Cambrian sandstone 50 feet or more at the quarry town of Sandstone and carved out at this place some of the largest potholes thus far known, a few miles below, where the Keweenawan eruptives are reached, but little cutting has been done. At Big rapids of the Kettle, where much erosion should be expected, only a few feet of Keweenawan rocks have been removed. Glacial striæ coursing south 5 degrees east, magnetic are seen only 3 feet above the water.

The Snake river, in a distance of 10 miles from Chengwatana to the Saint Croix, falls 130 feet, showing a still sharper gradient than the Kettle; yet at the former place it has cut into the lava beds upturned against its course not to exceed 20 feet at any place, and for the rest of its course has done but little beyond trenching the glacial drift deposits and soft Cambrian sandstones.

Other streams as well as these, gathered on the broad and comparatively level and wooded glacial plain to the north and flowing down over a rapidly descending slope into the Saint Croix, show identical physical conformations. Lava flows are only slightly eroded, and the cascade stage is the principal feature. This is true of Tamarack and Crooked creeks, which, within a direct line of some 20 miles, fall 350 feet and show a succession of cataracts for several miles. It is along the channels cut by these streams that the rock exposures lie.

EROSION OF THE DALLES OF THE SAINT CROIX

But still farther south at one or two localities, notably at the Dalles of the Saint Croix, a remarkable extent of erosion is seen. According to Doctor Berkey, the stream

"lies for nearly 5 miles almost without a break between parallel ridges of diabase standing on an average 1 mile apart and reaching an elevation of from 100 to 300 feet above the adjacent sedimentary rocks. . . . The present channel is not believed to represent the original location of the river, although smaller streams may have occupied portions of it. . . . All evidences indicate that the present Saint Croix River gorge is post-Glacial. . . . The chief factor in making the present channel the most available and permanent line of drainage was the glacial erosion accomplished at this locality. . . . At this time the volume of water discharged was abundantly sufficient to account for all the erosion phenomena

which seem so superior to the amount now carried by the Saint Croix river. Chief among these phenomena are the enormous potholes worn in these rocks (diabases) at Saint Croix falls and Taylors falls." *

A PRE-GLACIAL SAINT CROIX VALLEY

It seems that during the later Tertiary epochs the Upper Saint Croix valley was drained by a system of rivers somewhat different in direction from the existing streams and probably of quite different volume.

A glance at the topographic features of the map will show that the whole district was leveled to a remarkable degree before the Glacial epoch. In all the views bearing on the effectiveness of glacial erosion the admission is made that the gross topography of a region is only moderately changed; hence it is assumed that the broader topographic features now existing were imposed preceding the Glacial epoch by the usual processes of weathering and denudation.

Between the present Lake Superior basin and the Dalles of the Saint Croix is a notable Keweenawan syncline, stretching from the south shore of lake Superior southwestward for 150 miles, with a maximum breadth of not less than 75 miles, which probably drained southwestward into the Mississippi river at some point between Anoka and Saint Paul.†

Between the present drainage valleys of the Saint Croix and Mississippi to the southwest of Sunrise creek is a broad and nearly level sand plain, scarcely more than 900 feet above tide, while the Saint Croix at present runs in a narrow valley past the mouth of Sunrise creek at 760 feet above tide. These figures show, as Upham points out, a difference in elevation of not more than 150 feet.

The elevated ridge which forms the so-called "Copper range" of northwestern Wisconsin is a natural divide to the north and northwest between the waters of the Saint Croix valley and those flowing northward, while the continuous ridge of diabasic rock stretching from Keweenaw point to the Dalles of the Saint Croix forms an equally natural divide to the southeast. The region included between these bounds, formed by the upturned edges of the Lower Keweenawan eruptives and reaching to the Mississippi river, comprises a well defined drainage area of some 8,000 to 10,000 square miles, whose limits were readjusted at the time of the glacial invasions.

Doctor A. H. Elftman, who, as well as Mr Upham, has given some attention to the Saint Croix valley, aims to show that the Saint Croix river in pre-Glacial time flowed in a nearly straight course south from the mouth of Sunrise creek, section 32, township 36, range 20 west, be-

* C. P. Berkey: Geology of the Saint Croix Dalles. Amer. Geologist, vol. xx, p. 367.

† Warren Upham: Pleistocene ice and river erosion in the Saint Croix valley of Minnesota and Wisconsin, this volume, pp. 16–19.

neath the present famed Chisago lakes, until it emptied into the present Saint Croix valley, in section 7, township 32, range 19 west. This old Saint Croix river channel has been traced and its general course established through contour features and well-borings.*

ABSENCE OF LAKES

Another character of this district is the notable absence of lakes, inasmuch as the region on all sides stretches off into a veritable lake park. This physiographic feature, like that of the stream courses, is due to conditions dating from Glacial time.

To the north and west of the great Kettle moraine † is a wide belt of country extremely monotonous in its physical features. Swamps constitute a conspicuous feature. The friable Cambrian sandstones and the more varied clastics of the Upper Keweenawan offered slight yet equal resistance to glacial erosion.

Relation to the Associated Formations

THE UNDERLYING FORMATIONS

Nowhere in the eastern Minnesota area of the Keweenawan is its relation to the underlying formations seen; yet from observations along the Saint Louis river between Thomson, Minnesota, and Duluth,‡ along the Pigeon river, and around Grand Portage bay, § and along the north side of the Penokee range in Wisconsin, || it is clear that the Keweenawan is nonconformable on the earlier rocks. This nonconformity seems locally to be an eruptive one—that is, the separation is the intrusion of the later formation in the form of dikes and sheets thrust into the underlying strata or in extensive beds lying on the sedimentaries, and in other places the contacts of the older rocks and Keweenawan show a nonconformity by erosion between them. McKellar, Irving, and Merriam have pointed this out most emphatically for northeastern Minnesota and the Thunder Bay district.¶

THE OVERLYING CAMBRIAN SANDSTONES

Along the Saint Croix river, both in Minnesota and Wisconsin, the

* A. H. Elftman: The Saint Croix River valley, Amer. Geologist, vol. xxii, pp. 58–61.

† T. C. Chamberlin: Geology of Wisconsin, vol. i, 1883, pp. 275–287.

‡ N. H. Winchell: Final Report of Geological and Natural History Survey of Minnesota, vol. iv, pl. B, and pp. 13, 570.

§ W. S. Bayley: Rocks on Pigeon point, Minnesota, Bulletin 109, U. S. Geol. Survey, 1893, p. 23.

|| Irving and Van Hise: Penokee iron-bearing series of Michigan and Wisconsin, Monograph xix, U. S. Geol. Survey, 1892, p. 470.

¶ P. McKellar: Correlation of the Animikie and Huronian rocks of lake Superior, Proceedings and Transactions of the Royal Society of Canada, vol. v, 1887. R. D. Irving: U. S. Geol, Survey, Seventh Ann. Rept. Director, 1888, p. 387.

Cambrian series is practically horizontal, and lies directly on the Keweenawan lava flows. The sandstones are quartzose and remarkably pure. They carry but little Keweenawan debris in any section disclosed, save that the lowest layers locally carry pebbles, or, where conglomeratic, even boulders of diabase, as at Taylors Falls.

Along the Saint Croix, Kettle, and Snake rivers there are many exposures of these sandstones. While actual contact is not seen, the two formations are in such position as to leave no doubt whatever of nonconformable superposition. In sections 16, 20, 21, 29, 30, and 31, township 39, range 19 west, and thence interruptedly for a distance of 18 to 20 miles south, the sandstone lies in horizontal beds along the river bluffs which rise to a height of 200 feet, while beside the water the diabases and conglomerates persist in a series of westward-dipping beds.

STRATIGRAPHIC RELATIONSHIPS

From evidence gathered partly at distant points and partly from the explorations of the Keweenawan rocks themselves, the continuity of the Keweenawan from Keweenaw point to the Saint Croix River valley is established. The frequent recurrence in the intervening area of the same kinds of rocks with the same structure and stratigraphic relationships seems to be incontrovertible evidence.

The Fault Line

EXTENT OF THE FAULT

Along the western border of the area an entirely unexpected relation of the Keweenawan and Cambrian has been discovered. A fault line has been traced which seems to extend from the north end of the area in a southwesterly and southerly direction as far as the Keweenawan series is known to extend. The junction between the two formations is thus apparently marked by a notable fault (see plates 27 and 28), on one side of which the more or less shattered eruptives lie, and on the other a shattered and in places upturned white to pink clean quartzose sandstone is seen. The quartzose sandstone is younger than the eruptive rocks in northwestern Wisconsin.

Here the faulting has been observed and described by Professor Grant.* The shattered condition of the diabase along the fault line is especially pointed out. The brecciation which subdivides the rocks into remarkably fine fragments along the contact zone, but becoming coarser with

* Preliminary report on the copper-bearing rocks of Douglas county, Wisconsin, p. 17. Published by the state, 1900.

distance, can be traced for hundreds of feet away from the sandstone. This breaking up of the rock is intensified by weathering. The several lava flows to be noted along this line dip strongly to the south. Angles of dip are reported, varying from 40 to 70 degrees in the Black River Falls and Copper Creek districts, while the alternation of amygdaloidal and compact phases of the rock are constant, giving the flows a thickness varying, Doctor Berkey, says, from 25 feet to 50 feet, and both the compact and amygdaloidal phases of the diabase are vigorously shattered. The sandstones which lie to the north of this fault line are relatively depressed below the level of the Keweenawan just described. They dip northward and away from the lava flows strongly at first and gradually less until at a mile or two from the contact a nearly horizontal attitude is assumed. These sandstones no doubt continue without interruption northward to the Saint Louis exposures, where they are found to dip southward at an angle of 10 degrees. The sandstones as well as the diabases are profoundly shattered at the contact zone and fault line and are generally bent upward, thus suggesting that the movement which produced the fault was an upthrust of the diabases along a fault plane sloping to the north—that is, beneath the sandstones.*

Farther northeastward, at Pratt, a small station on the Chicago, Saint Paul, Minneapolis and Omaha railroad, near the middle of township 45, range 6 west, the diabases are exposed at several places. They show all the salient features of the rocks described for the exposures to the westward. They are badly shattered. While ordinarily compact, they have suffered to a notable extent from weathering, and the local areas of amygdaloidal phases disclose the effusive nature of the rocks. This shattered condition is a strong index of the proximity of the fault line, which, if it continue eastward from the falls of Black river, must pass far to the north of these exposures.

At Ashland and probably in the north part of township 47, range 4 west, an artesian well has been sunk to the depth of 3,400 feet and the bottom of the pink medium grained quartzose sandstones was not reached. These rocks were continuous next below the glacial drift and lake deposits.

MINNESOTA LOCALITIES

With the foregoing evidence clearly establishing the fault-line contact of the Keweenawan and Cambrian in Wisconsin, we turn to Minnesota. The Cambrian sandstones are known to occur at a sufficient number of localities in northeastern Minnesota to establish their continuity from the Black River gorge, in Wisconsin, and Fond du Lac, in the Saint

* Ibid., pp. 19, 20.

Louis River valley, southward to the great quarries at Sandstone, on the Kettle river. Only the following localities need here be given where recognition has been reported: Section 35, township 46, range 18 west, a well has been dug to the sandstone; section 2, township 44, range 19 west, sandstone has been reached within a few feet of the surface; section 10, township 44, range 20 west, in the bluffs of Kettle river; this is not an extensive outcrop; section 11, township 43, range 20 west, where begins a practically continuous exposure of 15 miles of horizontal to gently dipping, evenly bedded, workable sandstone, extensively quarried at the town of Sandstone. Upon that evidence it may be considered as proved that the Minnesota beds beneath the drift in southern Carlton county, in the river gorge at Sandstone, around Hinckley, on the Kettle, Snake, and Saint Croix rivers, and beneath the drift at Pine City, North Branch, and Wyoming belong to one and the same rock series as the brown sandstones of Fond du Lac, Minnesota, and a whole series of localities in Wisconsin. The identification seems to be indisputable.

THE EVIDENCE OF ARTESIAN WELLS

The following data are given as bearing on the question of a fault line now under consideration: At Hinckley, Cambrian sandstone is quarried in the banks of Grindstone creek. A well was bored about 200 feet deep. In the bottom is the same sandstone as at the surface beside the creek. Four and one-half miles to the east, at about the same altitude as the village, occurs a contact of diabase and sandstone with every indication of a fault which the shattered condition of both adjacent rocks can give, yet lacking ocular demonstration at present. At Pine City, on the west shore of Cross lake, an artesian well is 700 feet deep. The first 230 feet are river sandstone and glacial drift, while the remaining thickness penetrated is beyond doubt Cambrian sandstone. One and three-fourth miles away the diabase flows stand at the level of Cross lake and form the natural barrier which causes this expansion of the Snake river. At North Branch an artesian well gives a depth of 195 feet, probably in glacial drift. The rapids in the Saint Croix river in the strike of the diabase flows suggest the presence of the Keweenawan rocks within 3 miles. At Wyoming a well 505 feet deep penetrates 176 feet of glacial drift and enters the Cambrian sandstones for an additional depth of 329 feet. The lava flows of Taylors falls reach a height more than 200 feet above the surface from which the Wyoming well was sunk. The distance between Wyoming and the Lower Dalles is 15 miles. Finally, at Stillwater, a well boring reached diabase at 717 feet below the surface, or within 25 feet of the sealevel. At Minneapolis a deep well reached

granitic rocks at 2,150 feet, or 1,225 feet below sealevel. Stillwater and Minneapolis are 24 miles apart.

Thus it is seen that along the north and west sides of this area of diabases and conglomerates there extends a sharp line of demarkation, clearly defining the area in those directions, and at the same time apparently separating these rocks as a geographic area from that other area assigned to the same geologic age, beginning near Duluth and extending northeastward beyond the international boundary, and constituting the great northeastern Minnesota area of the Keweenawan series.

It does not follow from this interpretation—namely, that faulting has been a factor in bringing about the separation of these two areas—that they did not in that earlier time, the days of eruptive activity and conglomerate building, form parts of one and the same geographic province, nor that they are not now, below the Cambrian, the continuous floor on which this oceanic deposit was laid down.

Exposures of the Keweenawan

EASTERN PINE AND CARLTON COUNTIES

Commencing at the north and on the very eastern border of Minnesota, we note that the northern edge of the Keweenawan enters the state from Wisconsin, pursuing a southwesterly direction, in section 12, township 4, range 1 west. The rocks at this point are covered with drift, but the exposures within comparatively short distances in either direction disclosed in the channels of the streams enable geologists to locate the place quite accurately. These exposures may be mentioned: Township 45, ranges 16 and 17; township 44, range 16; township 42, range 16, at several localities. The rocks have a southwesterly strike and a strong southeasterly dip.

TAYLORS FALLS

At this place and its environs is an interesting succession of lava flows, worked out by Doctor Berkey.* They are a part of the southwest extension of the volcanic flows of the Keweenawan, which are known to occur at Stillwater, at 717 feet below the surface. Structurally, they are a series of lava flows, often columnar in habit, of dark color, mediumly crystalline, and ophitic or porphyritic in texture, frequently both. The flows vary from 30 to 60 feet in thickness, they average 15 degrees in dip to the southwest, and represent a total thickness of nearly 6,000 feet. This does not probably represent the entire Keweenawan at this point.

*Chas. P. Berkey: Geology of the Saint Croix dalles, Amer. Geologist, vol. xx, 1887, pp. 377–383.

The unconformity between this series and the overlying Cambrian is most beautifully and typically shown at two or three places. This has become a classic spot for the downward delimitation of the Cambrian in the Mississippi valley.

The clastic rocks of the Keweenawan at Taylors falls are unique. They consist of a succession of volcanic breccias and tuffs alternating with the compact ophitic diabase of the lava flows. The breccias consist of angular fragments of diabase "imbedded in a matrix of finely crystalline secondary minerals, chiefly epidote and quartz."* They occur quite statedly between the successive flows, and when once recognized are an excellent guide for the recognition of the division planes between them. The tuffs do not occur so constantly. They are not in extensive masses; one place shows a thickness of breccia and tuff of 25 feet to 30 feet; elsewhere the thickness is materially less. The "particles vary in size from mere dust to the size of an ordinary sand grain, and in the amount of abrasion to which they have been subjected from roughly angular to beautifully rounded grains." †

Doctor Berkey observes that this is one of the localities, noted in the geological literature of the Lake Superior district, where a well defined tuff derived from volcanic ash occurs.

No interbedded conglomerates have been detected at Taylors falls.

THE SAINT CROIX RIVER SECTION

This section comprises the rocks around the junction of the Snake and Kettle rivers with the Saint Croix. The farthest exposure upstream at the Kettle River rapids, and consequently the lowest rock seen in this district, is a conglomerate. Its thickness seems considerable. The texture is that usual in the series. At the time the locality was visited high water prevented a careful examination. At this point, and continuously down the river for some miles, the best exposures are on the Wisconsin side and the numerous islands along this portion of the river. The conglomerate named is followed by one or more lava flows; after these another conglomerate bed occurs; other lava flows follow this, and then another conglomerate bed. The entire succession in this group of exposures strikes steadily south 10 to 15 degrees west and dips westerly at an average angle of 12 degrees. This last named exposure is in section 29, township 38, range 19 west, and has been explored quite extensively for copper, as have the associated diabases, by Mr D. A. Caneday, who has given much valuable information on the geology of the district. The thickness of the rocks along the Saint Croix at this point cannot be

---

* Ibid., vol. xxi, 1898, p. 145.

† Ibid., p. 146.

determined with accuracy; the estimate, based on as careful measurements as were possible, is 2,500 feet for the length of the rapids.

The lava flows at this point in the Saint Croix river valley show an important feature wanting at Taylors falls. Here, without an exception, the flow consists of three parts: 1, a finely crystalline, and in places apparently devitrified porphyritic basal layer of a few inches thickness; 2, a medium grained uniformly crystalline middle portion, and, 3, a distinctly amygdaloidal upper division (see figure 1, page 328). The amygdaloid varies greatly in structure; usually in the central portion of the flow it is compact, the occasional vesicles becoming more and more numerous upward until in many cases, filled with zeolitic minerals, they constitute the major bulk of the rock.

It is this amygdaloid and the associated conglomerates that are explored so persistently for copper. Small quantities of the metal are found in many places, but those great segregations necessary for the establishment of mining operations are yet undiscovered.

The especial point of emphasis in the geology of this locality is that the Keweenawan rocks dip sharply and distinctly westward! Former investigations have placed them in the same series of eastward dipping flows as appear along the Snake and Kettle rivers. Irving,* among others, is led to this generalization from the eastward dip of the rocks on these two streams and the same direction shown on the Saint Croix some 30 miles above the mouth of the Kettle river. It is not maintained here that they are different flows; on the contrary, they may be the very same, but displacements of a profound character have disturbed the rocks along the west side of the district where the fault line exposes the upthrust edges of thousands of feet of lava flows and associated conglomerates. These conglomerates, in fact, may be continuous from the east to the west of the district.

The Cambrian sandstones which overlie the Keweenawan just described are of a cheerful pink color and usually of a medium texture. About 30 feet above the base there is a layer some 6 feet in thickness, filled with quartz pebbles of ¼ to ½ inch in diameter. These pebbles constitute not more than 3 per cent of the entire rock mass; scattered, as they are, without regularity in their arrangement, they form a very unusual phase of sandstone conglomerate.

That the horizontal, non-indurated sandstones of Taylors falls, the pink sandstones of the Saint Croix at this locality, the quarry rock along the Kettle river, the Hinckley sandstone, and the 700 feet of light colored quartzose sandstones penetrated at Pine City are all of one and the same body of Cambrian sediment, no longer seems to admit of the slightest

* The copper-bearing rocks of lake Superior, Monograph v, U. S. Geol. Survey, 1883, p. 245.

doubt. They are therefore here regarded as one and the same, and no discussion of their age will be entered upon.

THE SAINT CROIX COPPER RANGE

It is in the small area lying within townships 42 and 43, range 13 west, and northeastward that the highest Keweenawan rocks of the district lie. Along the north side of the Saint Croix river and within the bed of the stream is seen a series of sandstones and conglomerates extending for some miles. Strong describes these rocks, according to Chamberlin, as follows: They consist "of a red sandstone approaching in its variations a fine conglomerate on the one hand and an arenaceous shale on the other, and containing, embedded in it, fragments and thin leaves of shale. An examination of the granular ingredients shows that it was derived mainly from the crystalline igneous beds of the series. Its dip appears to be 10 degrees to the southeast."* The highest beds of the Keweenawan in this entire district are, according to Irving, at the Indian village in the northwest quarter of section 21, township 42, range 14 west.† These beds are mapped by him and the Wisconsin geologists as Upper Keweenawan. It would seem that they disappear before the Minnesota exposures are reached. The Kettle River lava flows and intervening conglomerate beds are so like all exposures of the Lower Keweenawan that they have been with but little reserve relegated to that subdivision. If these be Lower Keweenawan, there is no Upper Keweenawan in this part of Minnesota.

KETTLE RIVER

Along the Kettle river there are many interesting exposures of lava flows and conglomerates. The westernmost are in section 22, township 41, range 20 west, mentioned in the discussion of the western fault line. On both sides of the river almost a contact is seen between the diabase and the youuger Cambrian sandstones. The exposures extend on both sides of the river for nearly a mile. On the north side in a ravine dry for the most of the year the amygdaloidal diabase stands up in a sharp line of exposure nearly in the direction of the strike, dipping some 40 to 50 degrees to the east. On the west bank of the ravine, and scarcely 10 feet away from the amygdaloid, the broken sandstone stands in an abrupt escarpment. The sandstone must show not less than 75 feet with no evidence of the bottom layers in sight. Along the entire distance of the contact the attitude of the sandstone is that of a greatly disturbed

* Geology of Wisconsin, vol. iii, 1880, p. 424.

† R. D. Irving: The copper-bearing rocks of lake Superior, Monograph v, U. S. Geol. Survey, 1883, p. 246.

formation; it is broken into blocks, some of huge dimensions lying in many different directions. They have every appearance of being shattered by profound crustal movements.

Farther down the river, particularly in section 35 of this same township, are some well marked bluffs on the east side of the river, formed where the stream cuts into amygdaloid beds in the direction of the strike. The strong east wall is of the crystalline compact portion of the flow next above an eroded amygdaloid. A series of benches is noted in places where the direction of the stream has caused a transfer of erosion to the westward from one amygdaloidal layer to another still lower. The diabases dip east 40 degrees and more; the strike is, in general terms, south 10 to 15 degrees west, magnetic.

In sections 10 and 15, township 40, range 20 west, are several low exposures. They consist of the two usual varietal phases, massive and amygdaloidal. Their attitude was carefully taken and the average measurement is: strike, south 10 degrees west; dip eastward, 50 degrees—an average which shows a steady relation to the exposures farther up the river. If the strike and dip be practically unchanged, this easternmost locality represents a thickness of 5,000 feet from the fault line.

For several miles the river runs in a southeasterly direction and thus cuts diagonally across the strike. Whenever a flow of more than usual hardness is crossed a reef is found.

In section 24 of the same township occurs in the banks of the stream a conglomerate. It appears to dip westward at a low angle. We have here probably the first westward dipping Keweenawan met in descending this stream. It lies from 1½ to 1¾ miles in a direct line eastward of the strike of the exposures in section 15, which most certainly dip eastward. The axis of the syncline is therefore located within a few hundred paces.

It would thus appear from the nature of the rocks in evidence that the great thickness of the upper Keweenawan sandstones lying along the Saint Croix river in township ranges 42, 43, and 44 has wholly disappeared! Such must be the inevitable conclusion unless the small exposure of westward dipping conglomerate in section 24 be a remnant.

In section 19, township 40, range 19 west, occur the Big rapids of the Kettle river. The stream falls many feet within a half mile, tumbling over a succession of westward dipping diabases. At one place favorable for measurement, the strike was north 20 degrees east and dip west 20 degrees north at 15 degrees. These rocks, on account of their varying hardness and attitude against the stream, that of a succession of dams, cannot form a single cataract.

This combined circumstance of rock habit and rock attitude doubtless

was a controlling factor in holding down to a minimum the erosion of the Keweenawan at this place. The amount is much less than that along the Snake river at Chengwatana.

Just below the Big rapids is a conglomerate bed 100 feet in thickness. It lies conformably with the lava flows. An average of several measurements gives strike south 10 degrees west, dip 13½ degrees west. The varying hardness of this bed forms a succession of reefs across the river, while its readier disappearance under erosion, as compared with the more crystalline lava flows, is the probable cause of the rapid cutting into the eruptives immediately above. There are quite diverse textural characters in the beds; some layers are of normal sandstone, while others are made up of pebbles of large size. Quartzite, quartz porphyry, felsite, red granite or augite syenite, gray granite, diabase, and diabase porphyry are among the rock species represented by these well worn fragments. Underlying this conglomerate are more lava flows in normal succession.

Continuing down the stream three other conglomerate beds are passed possessing the same general characters as the one below Big rapids.

A conglomerate of considerable extent lies in section 29 of this township. Its strike varies from north to south to south 10 degrees west, dipping westerly at angles varying between 8 and 15 degrees. Its fragments vary from ordinary sand grains to good sized boulders. Its thickness is estimated at 50 feet, and it is separated from the bed below the Big rapids just described by possibly two or three lava flows.

In section 32, township 40, range 19 west, a thin bed of conglomerate overlies an extensive bed of tuff. The color of this, as of the other clastic beds, is red, and the fragments making up the material of all the members of the series show an intimate relationship of the series from the lowest to the highest.

In section 8, township 39, range 19 west, lies the last and lowest conglomerate bed of the Kettle River exposures. Its thickness is estimated at 50 feet. It is more arenaceous than either of the beds already mentioned. In strike it bears more westerly than the others.

The lava flows which lie here alternating with the conglomerates just located possess strikingly similar characters. The compact lower and middle portions of each are followed by the amygdaloid. In one place, however, is an interesting variation from the standard type. Along a considerable part of section 32, township 40, range 19 west, lies a bed of tuff. The rock is so decomposed that specimens can scarcely be broken. Rather frequent calcite-filled cavities and veins occur. Crystalline layers are associated with others so soft and decomposed that specimens cannot be dressed from them. It may be mentioned in passing that this tuff

bed directly underlies the fourth conglomerate bed noted in the Kettle River succession. A tuff underlies the fourth conglomerate bed, descending the Chengwatana series.

THE SNAKE RIVER LOCALITIES

So far as seen, the rocks of the Keweenawan along the Snake river are confined to the first 3 miles below Cross lake. This lake is a beautiful sheet of water 5 miles long, formed through the obstruction of the belt of Keweenawan rocks to stream erosion. Where the Snake empties into the Saint Croix there are several fine exposures of Cambrian quartzose sandstones, typical erosion cuts in modified drift, and an extensive area of eolian debris lying on the modified drift and river gravels. The Keweenawan lies opposite on the Wisconsin side of the Saint Croix.

THE CHENGWATANA SERIES

GENERAL STRUCTURAL CHARACTERS

The lava flows.—The name Chengwatana has been assigned for facility of description to a series of eruptive and clastic rocks of unusual extent. The flood of 1898, which tore away the dam at the foot of Cross lake and poured down the river gorge a vast volume of water, cleaned out in an admirable manner for examination the channel of the stream for several miles.

The Chengwatana dam rests on diabase. This rock occurs as a succession of lava flows. Each flow is characterized by three readily distinguished divisions: (1) A lower massive part, finely crystalline, finely shattered, and only a few inches in thickness. Its rough and irregular bottom layer gradually becomes more coarsely crystalline upward until it mingles into (2) the main mass of the flow. This part is of medium texture, dark color, and quite free from amygdules or other cavities indicating the presence of gaseous ejecta when solidification took place. There is some difference in texture as different flows are compared. The thicker ones are coarser and more distinct in their crystalline characters, and the ophitic habit is far more pronounced; they are more coarsely jointed; the rock seems fresher. (3) The upper portion, which is amygdaloidal and in several instances tuffaceous. The upper surface of each flow is rough, sometimes showing considerable erosion. On this surface the next succeeding flow adjusted itself in such manner that there is no difficulty in detecting the division plane between the amygdaloid and the finely crystalline and sometimes devitrified bottom layer of the next succeeding flow. The amygdaloidal holes vary in size from

minute spherical cavities to those the size of marrowfat peas. Occasionally some are larger and vary greatly in shape from the usual spherical and elliptical form. All are filled, or partially filled, with secondary minerals. Laumonite seems to be the principal one, while calcite is abundant. Locally the cavities have a lining of quartz attached to the wall in a crystalline film from which project toward the center of the cavity numberless pyramids of quartz crystals. These cavities now appear to be only partially filled.

The flows, of which the foregoing is a generally applicable description, extend in continuous superposition down the river for nearly 3 miles, those at the dam being the bottom of the visible series. There is great

FIGURE 1.—*Sketch across a typical Lava Flow, Chengwatana Series.*

This flow is 30 feet thick and lies between two conglomerate beds.

diversity in thickness. In fact, in the entire distance there are no two alike, either in total thickness or in the proportions of the compact and amygdaloidal parts into which every flow can be subdivided. The thinnest flow is not more than 8 feet in thickness, yet it presents all the characters of the thicker ones. From this thinness all measurements are noted up to 200 feet, the thickest flow seen in the series.

Associated with the foregoing structural characters are still others. Some of the beds display a conspicuous tendency to concentric weathering. As the blocks separate through temperature changes, and particularly freezing, the angles and edges disappear rapidly, and the material cracks and peels off in concentric layers which vary in thickness to some extent with the size of the blocks suffering disintegration.

There are color contrasts. All the rocks are dark; some are quite black, fresh, and ringing, while others are brown and dull, and when struck with the hammer develop a reddish powder which is perhaps the normal color of the decomposed rock.

The conglomerate beds.—Within this Chengwatana series of lava flows are no less than 5 conglomerate beds. The first one, descending the river from the bridge and dam along the south side, is reached in little more than half a mile. This bed is only 6 feet in thickness and made up of pebbles an inch and less in diameter. Quartz veins are conspicuous, running in many directions. The pebbles are much decomposed,

FIGURE 2.—*Concentric Weathering of Chengwatana Diabase.*

yet distinct enough to be recognized as of the volcanic material of this locality. Passing over 10 or 11 flows attaining a total thickness of at least 475 feet, another bed of conglomerate is reached, best seen on the north side of the river. Crossing another lava flow of 30 feet (see figure 1), of which 5 feet is a beautiful amygdaloid, a third conglomerate bed 102 feet thick is reached. This is the thickest conglomerate in the series. It resists weathering more strongly than the lava flows, as is shown by the prominent ridge which stretches northward from its outcrop until concealed beneath the glacial drift. Crossing 6 more lava flows, another conglomerate nearly 50 feet in thickness is found, and soon a fifth, but

thinner bed of this same clastic material is reached. This is identical in petrographic characters with the four preceding beds.

ATTITUDE OF THE SERIES

The attitude of all these conglomerate beds is substantially the same, and identical with that of the diabase flows, the strike being north 10 degrees east and dip east 67 degrees. Here and there are indications of slight movement, as slickensides and fractures; a few occurrences of a thoroughly fractured condition of the rocks is noticeable, but nowhere is a fault line seen. The inference is clear that the rocks from one end of the section to the other are continuous and represent a vast succession of flows and clastic beds lying one on the other without a break.

THE LIMITS OF THE SERIES

It must be assumed that the lava flows at the dam, while not determined to be lowest, are among the bottom flows of the series. There is an absence of any surface features north or south suggestive of changed rock conditions; yet it must be concluded that the fault plane which the artesian well 1¼ miles away brings into such strong probability is quite near the dam.

It is no easier to assume the eastern limit or top of the series. The easternmost exposure is said by Mr J. F. Stone to be near the mouth of a small creek entering the Snake in the southwest quarter of section 19, 2¼ miles across the strike from the lowermost flow in sight at Chengwatana. The dip at this point is said to be the same as at points well exposed--that is, around 67 degrees east; yet if the lava flows exposed on the Kettle river be projected across the intervening country to the Snake river, the strike of the uppermost flow seen on the former stream will cross the latter near the middle of section 28, or 2¼ miles due east of the exposure in section 19, just mentioned. Thus a total distance of 4½ miles is secured as the breadth of the western side of the great syncline which stretches from Keweenaw point southwestward beyond Stillwater, Minnesota.

THICKNESS OF THE CHENGWATANA SERIES

The total thickness of the 65 lava flows measured and their associated conglomerate beds is over 4,000 feet (see plate 27, figure 2). This is not all the series; the distance across the strike to the point in section 19 where the rocks are last seen is 2¼ miles; at the same eastward dip, as was measured on the rocks in sight, the total thickness to this point is 10,940 feet; yet the exposure in section 19 is only one-half the distance to the line

of strike of the easternmost eastward dipping exposures seen and measured on the Kettle river. Assuming that the dip of the first half be that at Chengwatana, and of the remaining distance that on the Kettle river, section 15, township 40, range 20 west, namely, 50 degrees east, the total thickness of the flows and conglomerates of the Snake river is nearly 20,000 feet. In view of the fact that nowhere in Douglas county, Wisconsin, on the Kettle river, nor along the Snake has any evidence of faulting been seen within the flows beyond the ordinary slickensides incident to the upturning of such enormous masses of rock, this must be regarded as a very conservative estimate of the thickness of the series.

Again this thickness, taken in connection with the measurements shown by Irving for the north shore of 22,000 feet; the Keweenaw point succession of 25,000 feet for the lower division alone, and that at Maimaisne promontory, 20,000 feet, is an easily conceivable amount; yet for a district so far away from lake Superior, it is certainly unexpected.

PETROGRAPHY OF THE SERIES

Structural characters.—The conglomerates require but a word of further description. They have been described in several paragraphs stating their salient field characters. They show here and there some evidence of crushing; slight faulting is rarely seen. The compacting of the rock until the finer particles or matrix of the pebbles begin to assume a crystalline aspect, as shown in the Keweenawan conglomerates farther north, is nowhere detected. Veins are rather rare, and when seen are not more than 2 or 3 inches wide. As a distinct rock, sandstones need not be mentioned, since they are associated with the conglomerates simply as local modifications of them. Ripple marks, cross-bedding, interpolated boulder beds, etcetera, are among the usual structural features of the finer layers. The breccias and tuffs of Taylors Falls present no special structural characters. The diabases occur in a series of lava flows possessing the usual structural characters of such rock masses. In every part great changes from the original condition of the rock are clearly in evidence, and they seem to bear close relationship to the physical condition of the lava beds. If badly shattered, the mineral condition is largely changed; if compact or fractured but slightly beyond the ordinary conversion of a crystallizing mass into blocks, their sections exhibit a rock of much freshness. A few of the flows exhibit a markedly concentric weathering (see figure 2). Samples can be broken showing a dozen or more concentric layers which peel off readily under the hammer. More rarely, and yet among the freshest rocks anywhere seen, is an apparent banding. When rocks are broken sufficiently deep, this proves to be

related to the arrangement of minerals with each other somewhat as gneisses differ from granites.

The amygdaloids are not peculiar. They vary greatly, of course, in frequency of vesicles and in the mineral species filling the same.

Textural characters.—The principal factor in determining the texture of the diabases would seem to be the thickness of the several flows of the diabase succession. In the field it is seen that the flows measuring but a few feet in thickness are finely textured. There is nowhere in the midst of the flows any trace of an existing or of a past vitreous condition beyond the finely crystalline and greatly altered bottom layers, which bear frequent evidence of devitrification. The porphyritic habit is often developed. This seems to be more characteristic of the thicker flows and the amygdaloidal layers than of the more usual rock masses of compact habit.

Lithologic characters.—Lithologically considered, the rocks must be discussed under two divisions, clastic and eruptive. Incidentally the entire area is brought in review.

The clastics are, first of all, conglomerates. While exhibiting a wide range in texture, they occur in several well defined beds, which are in the profiles carefully indicated. Their color is prevailingly red or reddish brown. They represent a wide range of material—diabases, amygdaloids, diabase porphyrites, gabbros, granites, felsites, quartz porphyries, quartzites, sandstones, and others. Boulders as large as 20 and 24 inches in diameter occur, but usually of average size. It is seen at once that this material was derived from a comparatively large geographic area, as well as a wide petrographic province. All the rocks named occur in the Lake Superior basin and upper Mississippi valley, but several of the species are not now known to occur within 50 and 75 miles of these boulders, nor have they been seen anywhere to the south of the beds. Other rock species—that is, vitreous quartzites—again, have been seen nowhere to the north, but they do occur in extensive formations east and southwest of this locality. No fossils have thus far been found. Native copper is present, but in such small quantities that mining operations have never passed beyond the exploratory stage.

Doctor Berkey was the first to note the occurrence of clastic rocks within the eruptive flows at Taylors Falls and Saint Croix Falls. Instead of intraformational clastics, he considered them simply as breccias, formed intermittently throughout the period of volcanic activity.* The breccia as a rock type is very obscure, since it is as hard and compact as other portions. Close inspection discloses that the fragments of diabase are irregular, of all sizes, and lie imbedded in a matrix of finely

* Geology of the Saint Croix Dalles. Amer. Geologist, vol. xxi, 1898, pp. 145, 146.

crystalline secondary minerals, chiefly epidote and quartz. It occurs in the division zones between flows. A volcanic ash was discovered at division planes between flows, a discovery which substantiated in a very convincing manner the subdivision of the series as indicated.*

A breccia between lava flows occurs whenever the surface of a flow is sufficiently vesicular and ragged to be crushed into a broken mass by the weight and movement of the next succeeding lava stream. The material is therefore excellent evidence of the existence of a succession of thinner flows instead of a single enormous outpouring of material. Locally there would be accumulated an abundant mass of cindery debris. If this be rolled beneath the advancing stream, a gravelly habit could be induced. Such seems to have been the case at Taylors Falls, and the material is in no sense to be regarded as an intraformational conglomerate, if Doctor Berkey be correctly interpreted.

Geikie, in his discussion of agglomerates, defines these products as "the coarser fragmentary materials thrown from volcanic vents,"† and these again are angular or rounded; the angular, collected in sheets or strata outside the vent, if coarse is breccia, and if finer is comprehended under the general name of tuffs, while the rounded materials are conglomerates or sands, according to the state of comminution. Among the earlier explosions of a volcano, fragments of non-volcanic rocks may be included in the pyroclastic detritus.

At Taylors Falls the brecciated habit of the rocks under consideration is obscure, owing to the hard and compact nature of the rock. Indeed, this rock is fully as resistant as other portions of the mass. Inspection shows that it consists of fragments of diabase, "angular, irregular, and of all sizes, imbedded in a matrix of finely crystalline secondary minerals, chiefly epidote and quartz."‡ Its place of occurrence is along the division zone between two flows. At other division zones a minerally saturated and now compact ash was subsequently discovered and accepted as confirmatory proof of the accuracy of the earlier conclusion touching the incidental nature of the breccia, and the association of the two is taken as proof of the existence of a series of lava flows at this locality instead of an enormous dike, as is too commonly supposed.

In quantity the amount of breccia and tuff in the Minnesota localities is small compared with the enormous masses noted by Geikie in his examples § of volcanic activity during the Tertiary volcanic period in Britain, and by Iddings around Electric peak.‖ Another character of

* Ibid., p. 145.
† Ancient Volcanoes of Great Britain, vol. i, 1899, p. 31.
‡ Berkey, loc cit., p. 145.
§ Sir A. Geikie: Ancient Volcanoes of Great Britain, vol. i, 1897, p. 32.
‖ The eruptive rocks of Electric peak and Sepulchre mountain, Yellowstone National Park. 12th Ann. Rept. Director U. S. Geol. Survey, 1892, p. 634.

the breccia of Taylors Falls is its completely altered condition. It required the close discrimination of microscopic investigation to identify it. It had never been detected prior to Doctor Berkey's investigations by any of the geologists who explored the district. Breccias and tuffs are closely associated. They form a bed about 20 feet in thickness at its maximum. Their compacted character makes it difficult without close inspection to distinguish them from ordinary diabase. Volcanic breccias and tuffs will doubtless prove rather frequent rocks in the Lake Superior region. Clements describes them in the Crystal Falls district as attaining a thickness of 500 feet, and still no means was afforded of determining their total thickness.*

The eruptives display considerable variety of rock characters, due to their genetic habit—that of a series of lava flows. The compact and amygdaloidal phases with their several structural types have already been mentioned. The former is of a granitic to porphyritic, granular or ophitic textural habit; the latter texture is shown in the mottled appearance brought out by weathering, which in later stages develops into a deeply pitted condition of the surfaces. The examination of the locality does not show any relationship between position in the series and textural conditions. Locally, a porphyroidal habit is seen, confined in its distribution chiefly to the amygdaloidal phases of the rock.

The more conspicuous character of the diabases is a prevailingly dark color, which is in some flows a dark green to black; in others a dark brown. From these as foundation colors green obtains when the alteration has produced a considerable proportion of chlorite, and brown when a ferric oxide has formed.

Gradually and quite steadily upward from the bottom of each flow the texture becomes coarser. Texture is not always the same; it varies with the thickness of the flow, and thus becomes an item of evidence in working out the history of the units of the series. Locally, variations were noted. A concentric weathering is one variation. It occurs in thick and thin flows alike, but seems to be confined to the granular textured rock (see figure 2). In two or three other flows of a decidedly ophitic habit, banding is seen. Its origin is obscure, since it seems to run at right angles to the direction of bedding. The foregoing structures seem to occur without regard to the nature of the original or existing mineral constituents.

It is in the upper vesicular portions that the greatest changes are seen. These consist in the deposition of new minerals within the vesicles of the amygdaloid; in the form of pseudo-amygdaloid through the replace-

* The Crystal Falls iron-bearing district of Michigan. Monograph xxxvi, U. S. Geol. Survey, 1899, p. 141.

ment of the primary minerals in such a manner as to present to the unaided eye an aspect very like the true amygdaloidal structure. This pseudo-structure is not confined to the amygdaloid; it has invaded the lower and compacter portions of the flows and modified them to a greater or less degree.

Rock alteration.—Decomposition has progressed further in the amygdaloidal than in the compact portions. In many instances the amygdaloid exhibits a distinct flowage structure in the parallel arrangement of its constituent minerals, as well as in the elongated form of the amygdules. There is a marked mineralogical difference in the several flows of any given succession.

The secondary minerals.—The vesicles are more or less filled with secondary minerals, laumontite, calcite, quartz, epidote, kaolin, and chlorite being the more common ones. Sometimes the cavities are compactly filled from circumference to center, at other times only partially so. It may be that in these latter cases the material has suffered decomposition and removal, thus through a still more complex series of stages attaining existing conditions. Empty cavities are in some instances seen—a condition, it is suspected, due to the circumstance that they lie above the datum line of the formation, and are thus subject to the dissolving as well as depositing effects of percolating waters. The walls of such partially filled amygdules are finely textured and bear evidence of the rapid cooling incident to the gaseous filling and expansive force of the vapor of water with which the flow ascended and came into the zone of rock cooling and solidification. The usual phenomena of devitrification are strikingly clear in some thin-sections of the amygdaloid.

Source of the Eruptives

Nowhere in this region is there seen a suggestion of volcanic craters. The flows beginning to the eastward of Pratt, Wisconsin, and extending west and southward beyond Chengwatana, Minnesota, are traced from river gorge to river gorge more than 100 miles. The contour of the country and its general petrographic habit, the lithology and physical characters of the rocks themselves, and the well known conditions of outpour and flow as seen in existing volcanoes do not suggest a single spot which may be regarded as the single seat of eruptive activity or the center of a group of volcanic vents.

Existing volcanoes pour out streams only a few miles long. Localities have been studied which afford a series of vents forming long volcanic lines. Such Geikie points out in Great Britain. In Iceland the craters are in rows so situated that they complement each other in the sum total

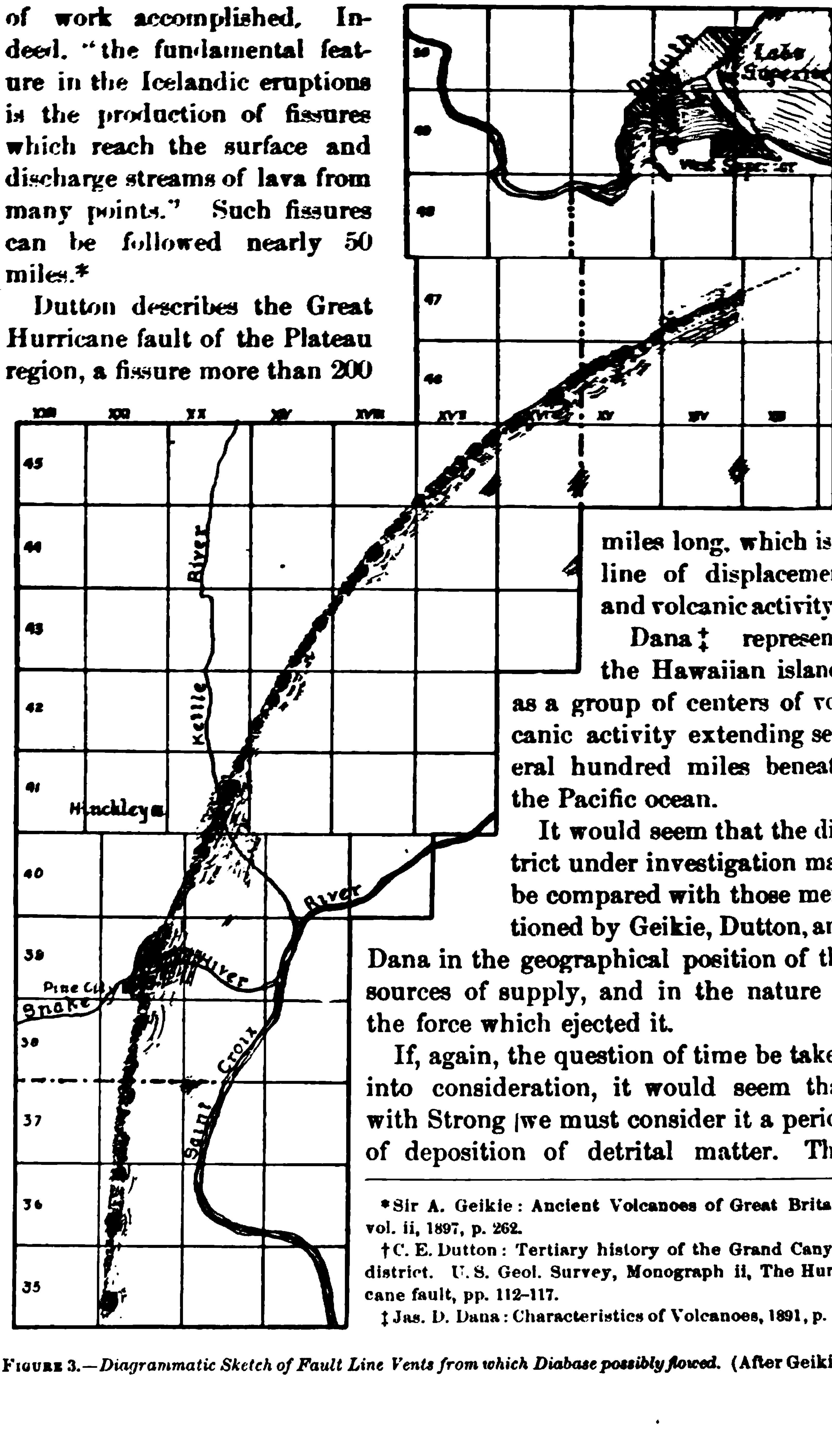
of work accomplished. Indeed, "the fundamental feature in the Icelandic eruptions is the production of fissures which reach the surface and discharge streams of lava from many points." Such fissures can be followed nearly 50 miles.*

Dutton describes the Great Hurricane fault of the Plateau region, a fissure more than 200 miles long, which is a line of displacement and volcanic activity.†

Dana ‡ represents the Hawaiian islands as a group of centers of volcanic activity extending several hundred miles beneath the Pacific ocean.

It would seem that the district under investigation may be compared with those mentioned by Geikie, Dutton, and Dana in the geographical position of the sources of supply, and in the nature of the force which ejected it.

If, again, the question of time be taken into consideration, it would seem that with Strong we must consider it a period of deposition of detrital matter. This



*Sir A. Geikie: Ancient Volcanoes of Great Britain, vol. ii, 1897, p. 262.

†C. E. Dutton: Tertiary history of the Grand Canyon district. U. S. Geol. Survey, Monograph ii, The Hurricane fault, pp. 112–117.

‡Jas. D. Dana: Characteristics of Volcanoes, 1891, p. 26.

Figure 3.—*Diagrammatic Sketch of Fault Line Vents from which Diabase possibly flowed.* (After Geikie.)

period was repeatedly interrupted, but not suspended, by the igneous outpourings.* It is more in harmony with the accepted basis of geological chronometry to regard the period as one of long-continued detrital deposition interjected with the many separate beds of outpoured lava. The cataclysms incident to the formation of these lava flows, though striking in their results, were very brief in their activity and local in their prevalence, while the detrital accumulations must have been vast in their periods and widely represented by equivalent deposits.

Development of the Fault Line

Interpreting events in the light of the foregoing discussion, the following sequence is suggested in the development of the great fault line:

A line of weakness stretches westward and southward from the Lake Superior basin. West of the southern 50 or more miles there lay a belt of Keewatin sediments and eruptives not less than 15,000 feet in thickness extending into central Minnesota, while to the east of it there is not a trace of this load. Such a line of weakness once clearly defined by crustal conditions would naturally determine the position of that long line of volcanic vents necessary to afford the supply of lava in the flows of Minnesota and Wisconsin, so remarkable in number and long stretch of surface covered by them. A fault line was clearly determined, either before the lava was poured out or during the long period of alternating volcanic activity and sea erosion represented by the rocks herein described. The outpouring of lavas conspired with the uplift of the surface southeast of the fault line to raise the contiguous edge of the flows and tilt the rocks into the position they have assumed. The Cambrian sandstones, accumulating probably from areas eroded to the north and west, filled the sunken areas and overwhelmed the lava flows. The sliding of the rocks continued, and these sandstones became involved in the movement, so that now the junction of the Cambrian and Keweenawan is a fault-line contact along which the latter is crushed and shattered for 400 feet and more, according to Professor Grant,† and the former is profoundly displaced ‡ or broken and dislocated into blocks in such hopeless confusion that the formation attitude can not be determined. The amount of displacement is great; at Ashland, at least 3,500 feet; at Chengwatana, how much more than 700 feet can not yet be told.

That the faulting is great is further indicated by the heavy dip south-

* Geology of Wisconsin, vol. iii, 1880, p. 393.

† Preliminary report on the copper-bearing rocks of Douglas county, Wisconsin, p. 18 and pl. v. Published by the State, 1900.

‡ Ibid., p. 20 and pl. vi.

ward and eastward of the lava beds and associated conglomerates. The displacement must have been a continuous process, extending through several periods of geologic history; that it was partly pre-Cambrian is shown by horizontal sandstones lying on the edges of Keweenawan lavas, as in the Saint Croix valley; that it was post-Cambrian is shown by the contacts everywhere of crushed and shattered rocks, both Keweenawan and Cambrian; that it was intra-Cambrian is a strong probability in the problem, since Cambrian time was long and only in part represented by the rock formations of this region; that it was partly post-Ordovician is suggested by the beds of Trenton limestone in Washington county, Minnesota, lying 200 feet higher than the same beds at Minneapolis, both areas being horizontal and only 12 miles apart.

There is everywhere in the upper Mississippi and Saint Croix regions evidence that local crustal movements have been comparatively slight since Eo-Paleozoic time—at least, such displacement phenomena as we have described are not yet elsewhere shown.

Summary

The foregoing discussion may be summarized under the following eight propositions:

1. The district is quite level and unbroken, not only in its modern features but in those pertaining to every geologic age since the Keweenawan. River erosion is very recent, and its exhibitions of water work, save in the gorge of the Saint Croix, are post-Glacial. In that gorge are evidences of work performed during a pre-Glacial or inter-Glacial period of baseleveling.

2. The Keweenawan rests unconformably on the earlier rocks and is in turn overlain by the Cambrian in unconformable superposition. Its rocks represent a long period of sediment-building interrupted by seasons of volcanic activity. Judging from the character of the rocks formed during this time, the energy and frequency of the volcanic outbursts waned to a state of perfect quiet during the period designated Upper Keweenawan. Then the Cambrian was ushered in.

3. The eastern Minnesota Keweenawan area is a synclinal trough, each side of which is a series of lava flows and conglomerates. The succession along the east side, as seen in the gorge of the Saint Croix river, dips westward at 10 degrees about the mouths of Kettle and Snake rivers, where some 2,500 feet of rocks are in sight, and at 15 degrees southwestward at Taylors falls, where on both sides of the Saint Croix

river at least 6,000 feet of lava beds and tuff deposits occur. On the west side of the syncline the series is sharply defined by a fault line from which the lava flows dip eastward at a sharp angle. Along the Kettle river the dip is as high as 50 degrees, and on the Snake it reaches an average inclination of 67 degrees. These flows, as the outcrops on the two streams from 7 to 10 miles apart are correlated, attain a thickness of 20,000 feet, comparable in extent with the Keweenawan of the north shore of lake Superior along the Minnesota coast, the south shore on Keweenaw point, and the more extreme eastern beds of Maimaisne point.

4. The Snake River outcrops at Chengwatana are called the Chengwatana series. They exhibit a series of 65 lava flows and 5 conglomerate beds in continuous succession, with neither the base nor the summit exposed. The lava flows are typical, presenting the finely crystalline base, mediumly crystalline middle part, and amygdaloidal upper part strongly in evidence. The visible flows can be traversed for 3,500 feet in vertical thickness, while the entire series probably attains the thickness named in paragraph 3.

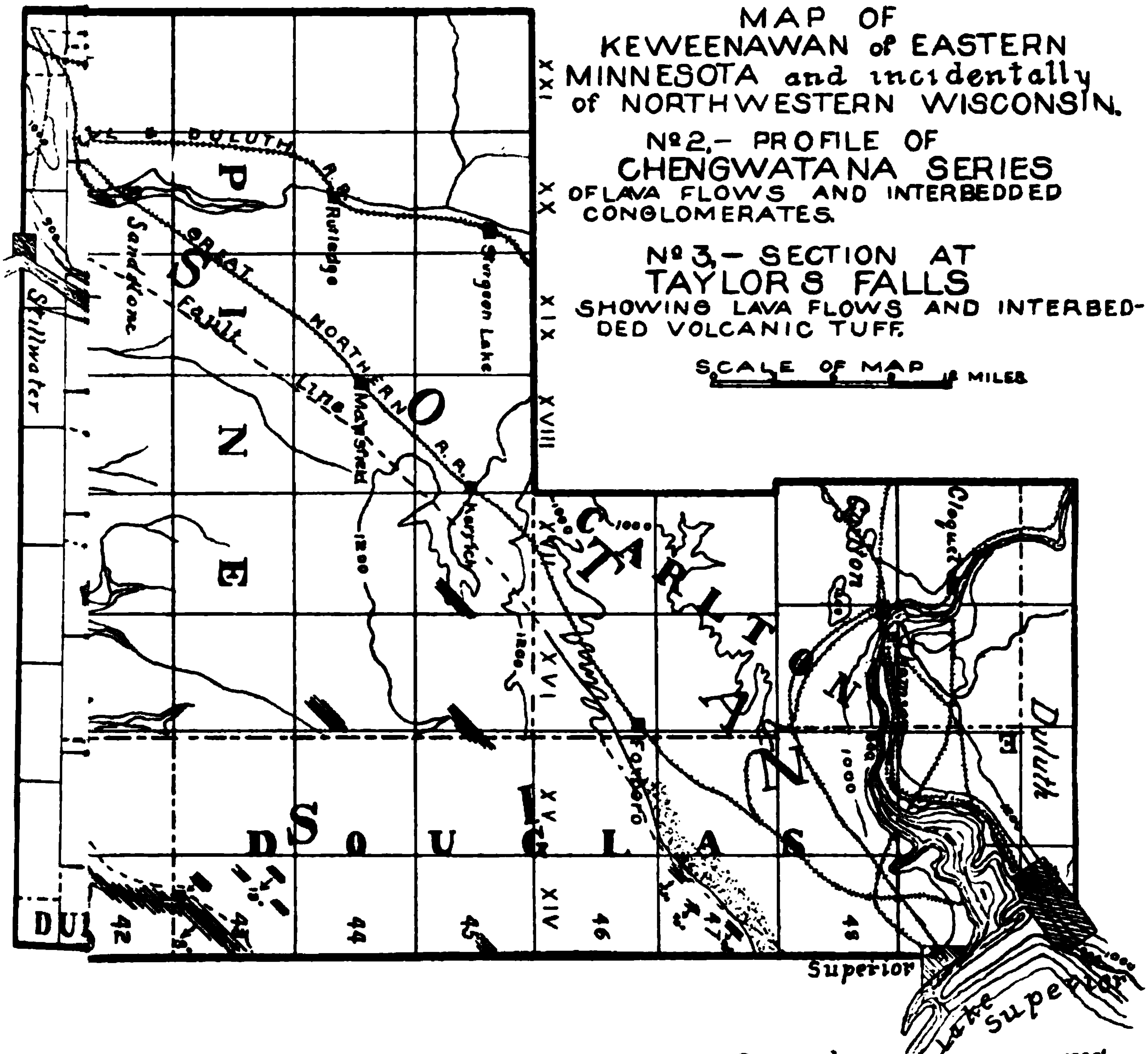
5. The petrographic characters are described as exhibited in the two groups of rocks, clastics and eruptives. The former are (1) conglomerates, with the specific characters incident to this region, and (2) breccias and tuffs lying between the lava flows and usually thoroughly consolidated. The latter are diabases, either compact or amygdaloidal, and usually of the ophitic type. The prevailing colors are dark. In places the mottled appearance prevails peculiar to ophitic diabases in the Lake Superior region. A porphyritic habit is here and there, and a marked concentric weathering is seen in a few of the flows.

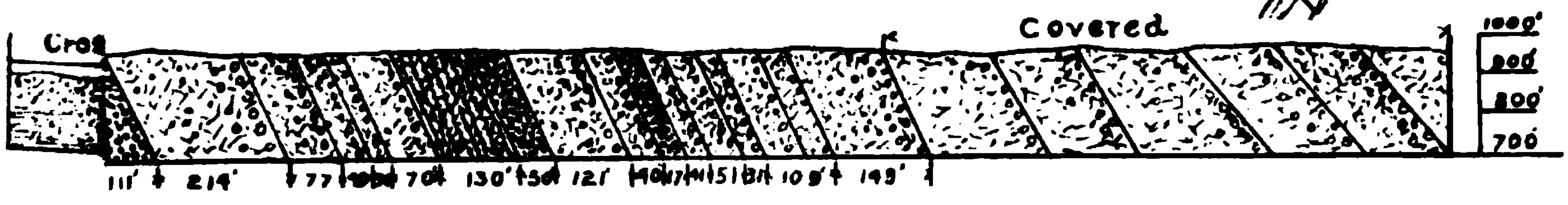
6. In discussing the source of the eruptives the failure to discover volcanic vents is stated, and the probability of a series of vents located along the fault line is named. The plausibility of this explanation is seen as the extent of the fault line is considered in connection with the large number of consecutive flows which can be counted along the west side of the syncline at several places, 65 being the number seen at Chengwatana. Localities of modern volcanic activity are mentioned in support of the view that the lava came from fissures which discharged material at many points.

7. The development of the fault line through a series of fissure eruptions and the line of weakness incident thereto is suggested. The tilting of the Keweenawan rocks to a sharply inclined attitude can be traced for more than 100 miles from the Lake Superior region southwestward.

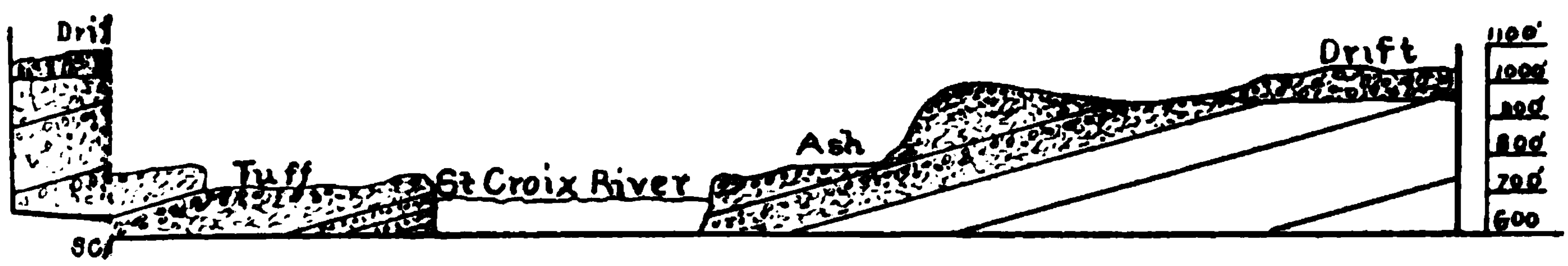
To the north and west of these sharply tilted rocks the Cambrian sandstones are, wherever seen, badly broken and inclined away from the faulted contact with the Keweenawan.

8. The formation of the fault line in its present attitude was a long continued process. The line of weakness and a succession of fissure eruptions is evidenced by the lava flows themselves. This is Keweenawan time. The crushing of the sandstones and their upturning is certainly post-Cambrian. The faults in Paleozoic rocks and the displacement of Trenton limestones between Minneapolis and Stillwater points to a continuation of the movement of displacement into the Ordovician.



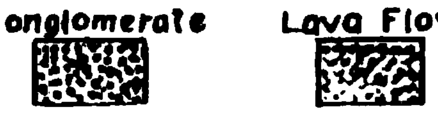


5 exposure



rlain by beds
r Berkey.

Conglomerate Lava Flow



TERN MINNESOTA

Explanation of Plates

Plate 27.—*Map and Profiles of the Keweenawan of eastern Minnesota*

Figure 1.—Map of eastern Minnesota.

This map of the Keweenawan area of eastern Minnesota shows the exposures of Keweenawan rocks; the position of the fault line which marks the limit of the Keweenawan to the north and west, and the assumed limit of the lava flows toward the southeast. The contour lines for Minnesota are taken from the several county maps of the Geological Survey of Minnesota; for Wisconsin approximated from the elevations of Upham and Gannett, Bulletins 72 and 160, United States Geological Survey.

Figure 2.—Profile of the Chengwatana series of lava flows and conglomerates.

The thickness of the several beds is given as measured along the banks of the river. The total thickness of the conglomerates is 216 feet and of the lava flows 3,800 feet, making a total of over 4,000 feet of exposed beds with both underlying and overlying beds concealed.

Figure 3.—The succession of lava flows at Taylors Falls.

This is as they are shown in the Dalles and along the slope westward through the village to the prairie level. At the top of several of the flows are beds of tuff and ash, and at one place there is a markedly brecciated clastic.

PLATE 28.—*Profiles across the Keweenawan Series of eastern Minnesota*

FIGURE 1.—Profile of the Snake River section.

At Pine City a well 700 feet deep ends in white sandstone assumed to be of Cambrian age. At the foot of Cross lake the succession of lava flows comes to the surface and extends along the river for nearly 3 miles in continuous exposure, dipping on an average east 67 degrees. Near the mouth of the Snake river the rocks dip 12 to 15 degrees west in a succession of lava flows which to the east disappear beneath Cambrian sandstones.

FIGURE 2.—The Kettle River section.

The lava flows abut abruptly against Cambrian sandstones near Hinckley, and for some miles along the river dip strongly to the east. The dip changes to west 12 to 15 degrees above the big eddy in section 19, township 40, range 19, and continues in this attitude until the rocks disappear beneath Cambrian sandstones on the Wisconsin bank of the Saint Croix river.

FIGURE 3.—Profile along the Minnesota-Wisconsin boundary.

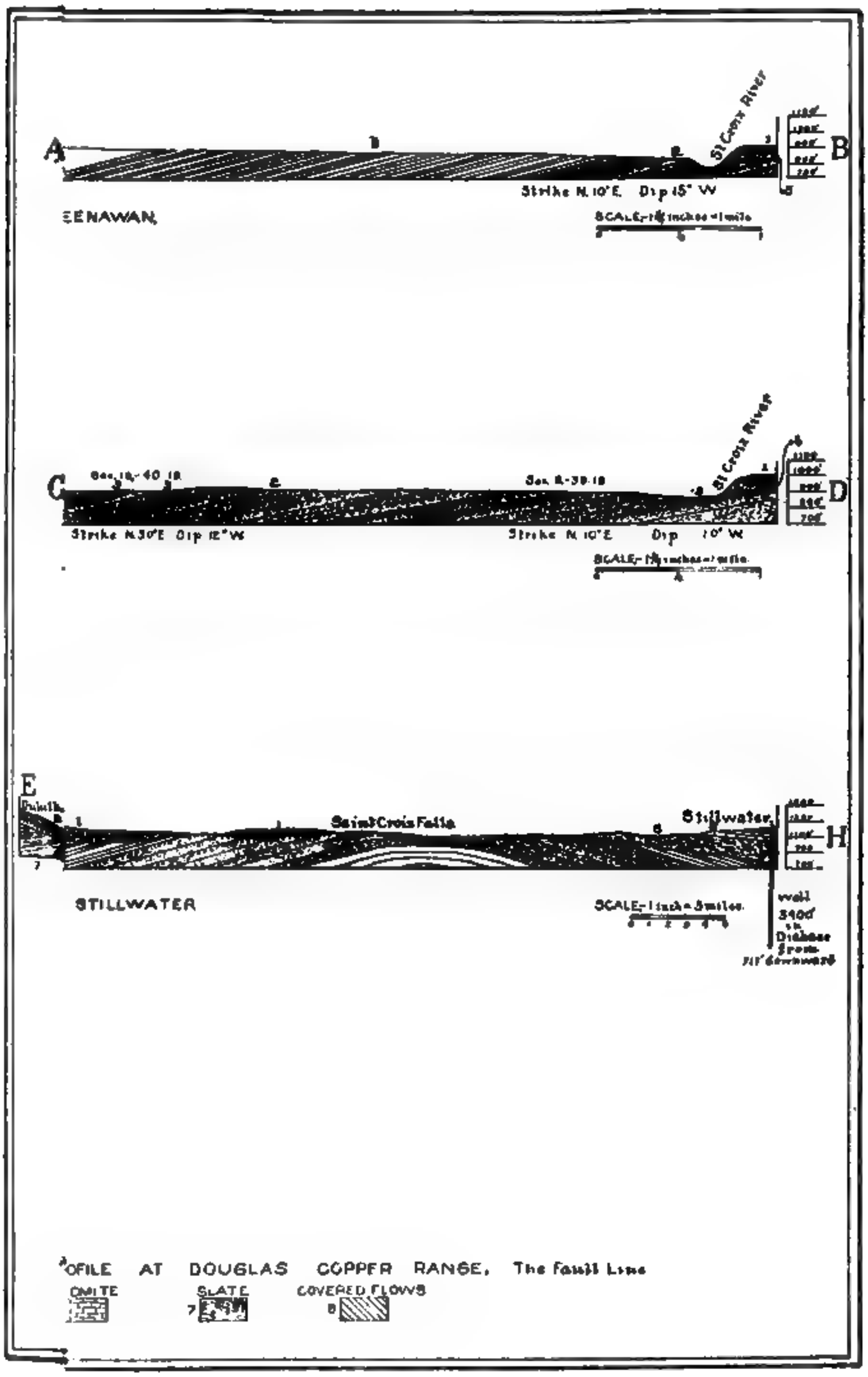
The profile is taken near the interstate boundary, *E F* from Duluth to the Saint Croix river, and *G H* from the Saint Croix near the mouth of the Kettle river to a point east of Stillwater. The lava flows near the mouth of the Kettle and Snake rivers dip west, and at Saint Croix falls to the southwest, and presumably so at Stillwater; hence the apparent change in dip.

FIGURE 4.—Profile across the Keweenawan and associated formations.

The locality is at Short Line park, in the western part of Duluth, and across the Douglas County fault line. The section in the western part of Duluth is as shown by the boring at Short Line park.

FIGURE 5.—Generalized section across the fault line, Douglas Copper range.

The rocks in their shattered and upturned position prove the upthrust of the lava flows.



RN MINNESOTA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 343-376, PLS 29-32 AUGUST 31, 1901

KEEWATIN AREA OF EASTERN AND CENTRAL MINNESOTA

BY C. W. HALL

(*Presented before the Society December 30, 1899, and December 28, 1900*)

CONTENTS

Introduction

Within Minnesota from the city limits of Duluth southwestward beyond the geographical center of the state, which is lake Mille Lacs, lies a series of schistose rocks. To the southeast they disappear beneath the Cambrian sandstones, and the northwest boundary is entirely concealed by the Glacial drift. Their existence in a few localities has been known since the earliest geological explorations of the region. They were first recognized as Archean; then as Animikie—that is, Upper Huronian; and lastly, in 1894, the northernmost exposures were pronounced by Spurr to be Keewatin—that is, Lower Huronian.

The pre-Cambrian age of the series, which has rarely been doubted, is proved by the presence at two or more places of nearly horizontal sandstones in such relation to the rocks in question as to establish their subsequent age. Again, at Short Line park, near Duluth, the series under discussion is found to lie in undetermined thickness beneath the diabase flows and associated rocks of the Keweenawan.* Finally, since dikes of granite are found breaking up the intruded schists within areas regarded as belonging to the series discussed, the post-Archean age of the granites is with confidence asserted.

Geographic Subdivisions

Along the Saint Louis river where it constitutes the interstate boundary a belt of slates and schists emerges from beneath the Keweenawan to extend in almost continuous exposure up the river to Cloquet. The exposures lie in force around Thomson and Carlton, where the rocks range through every textural phase from a graywacke conglomerate to a roofing slate of excellent quality.

In the Blackhoof River valley the schists appear above the thin covering of drift and stretch southwestward to the Kettle River valley, where

---

* Geological and Natural History Survey of Minnesota, final report, vol. iv, 1899, p. 567, 568.

they can be followed for 15 miles with but little change in textural or mineral characters.

West of Sturgeon lake the schists have become more hornblendic. The attitude is notably changed from a gently southward dipping series to one nearly vertical or northwardly inclined. Beds of limestone are associated with the hornblende schists.

Along the Kettle and Rum rivers still other conditions are seen. The schists are markedly biotitic and of a much coarser texture than in the Blackhoof and Kettle River valleys. Dikes of diabase occur and granitic dikes and bosses constitute the larger proportion of the visible exposures.

Reaching the Mississippi river from Haven northward for not less than 30 miles, only granites of the hornblende-biotite type, occasionally broken by diabase dikes and bosses of biotitic gabbro, are seen in so many exposures that the conviction is forced that they constitute the principal rock of the region.

Finally, in another district with Little Falls as a center lies a series of schists of somewhat diverse lithologic type, always regarded as the westward extension of the Thomson slates. These have many characters—mineral, chemical, textural, and structural—in common with those. Around Thomson the clastic character of the series is clearly seen. Here alteration has proceeded so far that no traces of a granular character have been noted—a condition explained by the proximity of eruptive granites, gabbros, and diabases within the Little Falls district (see map, plate 29).

Rock Relations along the Border

It has already been stated that at Short Line park, within the city limits of Duluth, a well-boring discloses the Saint Louis River slates beneath the Keweenawan eruptives, thereby establishing the northeastward continuance of the series. In this locality there is no doubt that the schists extend beneath the Keweenawan eruptives and clastics. In the southerly part of Kimberly township, central Aitkin county, an exposure of quartzite is reported, which, having the lithologic characters of the more northerly Animikie, is on that ground relegated to that later series.* At Brainerd, in 1900, a well was bored by the Northern Pacific railway. At 163 feet schists were struck of the general habit of those northwest of Little Falls, and are presumably the same.

Around the western end of the district there is no opportunity whatever afforded for determining stratigraphic relationships beyond the drift

* Warren Upham: Preliminary report of field-work, Twenty-second Ann. Rept. Geological and Natural History Survey of Minnesota, 1894, p. 28. ("Taconic series" is the term used.)

contacts and a few artesian wells. The last afford evidence of the superposition of the Cretaceous shales over the granitic rocks. At Glenwood, on the northwestern border, granitic rocks occur at a depth scarcely greater than 50 feet below the water of lake Minnewaska. At Paynesville, southwest Stearns county, not more than 12 miles from outcrops of granitic rocks, Cretaceous shales were discovered at 70 feet below the surface. How deep the crystalline rocks lie was not determined. At Glencoe, directly south of Saint Cloud, red quartzite rocks were reached at 936 feet and bored into 700 feet farther. Just where the southern subglacial boundary lies has not yet been determined. At Anoka, 40 miles from the most southerly granites, wells determine the presence of the Paleozoics, which extend thence down the Mississippi valley. At Minneapolis granitics were reached in the Lakewood Cemetery well at 2,150 feet from a point 975 feet above the sea. Along the east side of the district along which the crystallines disappear beneath Cambrian sandstones these disappear abruptly against the Great fault, determining the western limit of the Keweenawan lava flows.

The geographic limits of the rock series under consideration may thus be summarized: On the south, while disappearing beneath the Paleozoic, they continue beneath these beyond Minneapolis, Winona, and La Crosse, where well-borings have established the presence of granitic rocks; to the east as far north as township 46, range 16 west, while beneath Cambrian sandstones westward the schists are abruptly broken by the great Keweenawan fault; northeastward they slope beneath the Keweenawan; northward they must be overlain by the westerly stretching Mesaba; but to the west the glacial drift and Cretaceous so completely obscure the relations of the older rocks that it is now impossible to correlate with positiveness the central Minnesota granites and the Minnesota Valley gneisses and gabbro-schists.

Keewatin of the Saint Louis River District

Rocks of the Series and their Relations

In the bed of Mission creek, sections 30 and 31, township 49, range 15 west, near the boundary between Saint Louis and Carlton counties, lies the easternmost exposure of the Thomson slates. In the gorge of the Saint Louis river, where Mission creek joins it, the slates form the river bed. From this point they are practically continuous to Knife falls, a distance by river of 15 miles. The strike is east and west, the dip generally south, at a varying angle. Above Knife falls occasional exposures are seen as far as section 27, township 51, range 19 west.

The Saint Louis river between Cloquet and Duluth has accomplished an enormous amount of erosion. Several high and precipitous knobs are isolated from the surrounding rock masses through river erosion. Those in the northeast quarter of section 15, township 48, range 16 west, and extending over the adjoining sections are relatively the highest. They disclose interesting phases in the history of the stream.

The gorge is chiefly pre-Glacial. Lacustrine deposits, quite extensive both in area and thickness, lie along the slopes of the ancient Saint Louis valley. They are evidently the shoreline accumulations of lake Duluth * laid down in a valley already cut by pre-Glacial streams. Erosion was suspended during the life period of lake Duluth, but was resumed when lake Superior began to settle to its present level.

The descent of the land surface causes the rapids; the tremendous eroding power given the water by its descent has carved out the gorge called the Dalles of the Saint Louis river. Several diabase dikes cutting the slates produce the falls several times met within the length of the "dalles."

The Keewatin slates and associated schists and quartzites lie below all other known rock formations in this region. This group is of undetermined thickness, but is estimated at 25,000 feet. Above it are seen in the Saint Louis valley the following series, in ascending order:

1. The Keweenawan series, consisting of (*a*) the gabbro in typical development, regarded as the basal number of the Keweenawan; † (*b*) a conglomerate bed, 100 feet or more in thickness, and (*c*) the extensive series of lava flows which is found in many portions of the Lake Superior basin.

2. The horizontal Cambrian sandstones from red to white in color, known as the Western sandstone.

3. Pleistocene deposits, largely lacustrine sands and clays, and unmodified material.

EXTERNAL CHARACTERS

The external characters of the Keewatin of the Saint Louis river may be briefly summarized: In color the rocks are dark. The fine slaty phases are black, and as the quartzite bands appear this color gives place to a gray which varies between black and light or greenish gray. As the rock weathers, a lighter color appears, due to the removal of carbonaceous material which locally produces the black color. Toward the north the clastic character of the rocks is clearly expressed. There are

* B. F. Taylor: A Short History of the Great Lakes, 1897, p. 10.

† The copper-bearing series of lake Superior, Monograph v, U. S. Geol. Survey, 1883, p. 156. N. H. Winchell: Geol. and Nat. Hist. Survey of Minnesota, vol. iv, 1899, p. 13.

alternations of impure quartzite, so indurated that the coarser pebbles are fused with the finer material into a semi-crystalline mass and a typical argillaceous slate with prominent cleavage.

Irving* thus enumerates the rock species:

"Among the slates, fine grained graywacke slates, clay slates, sericitic quartz slates, true quartzites, mica slates (often hornblendic), staurolitic mica slates (often garnetiferous), and hornblende schists, and among the eruptives, diabases, gabbros, and diorites, the latter presumably altered forms of diabase or gabbro."

The rocks have been traced southwestward for many miles and found to merge into a series of well defined hornblende-mica schists. A total obliteration of clastic characters and an interbedding of carbonate bands is shown. Still farther southwest a distinct limestone formation enters the series and becomes genetically an important factor.

STRUCTURAL FEATURES

The strike averages south 70 degrees west, and the dip south at an angle varying between 10 and 60 degrees. The slaty cleavage, which usually can be distinguished from lamination, is nearly vertical, with a direction nearly east and west.

At Thomson in both the slaty bands and the schists are locally numerous carbonate concretions.

The slaty cleavage seems to characterize the layers of finer and more argillaceous material, alternating with the quartzitic and conglomeratic phases. It always ceases at the contact of the argillaceous and silicious layers. The angle which it makes with the plane of contact, assumed everywhere as the bedding plane, varies, since the bedding of the rocks several times across the formation changes its attitude with the horizon. The quartzite shows the effects of enormous pressure, yet the physical condition of the rock material, so much less plastic, was so resistant that the effect of slaty cleavage was not induced.

This alternation of quartzitic and slaty layers is a notable petrographic character along the Saint Louis river. It is distinctly seen through color differences, lithologic characters, and rapidity of weathering. The coarser material carries zones or planes of nodular concretions which are of a decidedly carbonated composition. Weathering brings out the position of these concretions rapidly and in a most conspicuous manner. They indicate bands of the sedimentary rocks which contained a much greater per cent of carbon dioxide in combination. Through the subsequent

* R. D. Irving: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 197.

alteration phenomena the segregation into nests of carbonates of iron, calcium, and magnesium was effected.

STRUCTURE AND DISTRIBUTION OF THE CONCRETIONS

Ordinarily these concretions are arranged in bands. As the rocks are eroded or cut away by human agency, the concretions stand in rows one above the other along the line of bedding. They are so compressed that they stand in the direction of the slaty cleavage, so far as individual position goes (see plate 31, figures 1 and 2); hence they give evidence both of original position and effect of pressure. They are undoubtedly of secondary origin; they consist chiefly of iron carbonate in chemical composition; they are quite well defined as against the mass of rock enclosing them, and weather with unusual facility and rapidity.

QUARTZ VEINS

There is a large number of quartz veins. The largest one noted is a segregation which stands up in the river bed where the carriage bridge from Carlton to Thomson crosses the Saint Louis river. It carries much of the slate and exhibits a heterogeneous quantity of quartz, and smaller quantities of pyrite, chalcopyrite, and traces of associated sulphides.

The smaller quartz veins scattered throughout the rocks diminish to paper thinness. They are milky white, harder than the slate and quartzite through which they course, and are remarkably free from accessory minerals. The closest scrutiny of explorers has failed to find more than traces of gold and silver.

DIABASE DIKES

The somewhat frequent dikes are objects of interest. The greatest width noted is 50 feet in one crossing the slates and quartzites one mile southeast of Carlton on the Northern Pacific railroad. The rock is diabase, extremely finely textured along the contact zones, and mediumly crystalline in its central part. At 50 paces east of railway bridge between Thomson and Cloquet is a 3-foot dike showing on a smaller scale the characters noted in the preceding; and many other similar structures are to be seen, but nowhere, so far as observed, do they exert any perceptible alteration effects upon the slates and quartzites into which they have been injected.

JOINTS AND FRACTURES

Jointing is everywhere one of the most conspicuous characters. The sharp ridges which, through the slate belt, are a conspicuous physio-

graphic feature, are due in a large measure to jointing. The jointing which has developed along the bedding, constituting the major structure on the southward slopes and a system of fractures in which there are frequent evidences of shearing, give character to the northward slopes.

Aside from the major structures, there are minor ones which vary with the condition of the rock.

Several efforts have been made at Thomson and near Cloquet to quarry roofing slate. The color is black, weathering to a light gray. The layers of slate, intercalated between corresponding layers of quartzite schist, are from 1 to 5 feet in thickness. Each layer is cut by many joints into plates. These joints, always striking with the rock or within 10 to 20 degrees of the same direction, make an angle of 30 to 40 degrees with the bedding planes, which at the slate quarries in Thomson dip south at from 65 to 75 degrees, and at Cloquet are nearly vertical. For several hundred feet the slate has been worked out, but a persistent warping renders the product of inferior quality (see plate 31, figure 1).

The Blackhoof Valley

Around Atkinson are several outcrops of quartzite schists. The strike is north 70 degrees east, magnetic, and the dip south at an angle of 65 degrees. Farther southeast the dip, continuing southerly, drops to about 25 degrees. The rocks locally assume a decidedly contorted condition. The exposures are not numerous, but the rocks lie only a short distance below the surface, and upon these an abundant and excellent water supply is always found.

The rocks separate freely along the schist planes, and are cut into somewhat rhombic blocks by a double system of joints, one of them being nearly coincident with the dip. A light and cheerful slate-gray color characterizes the more typical exposures. The freshly cleaved surfaces are quite lustrous. As these schists merge into a softer talc-like condition, as is the case where the concretionary lenses of quartz or quartz and siderite occur, the color becomes still lighter, or dark even to blackness. At one exposure, graphite was noted along the cleavage banks. To this source the black color sometimes seen is referred.

Some years ago explorations for gold were prosecuted along belt of quartz veins which resulted in finding only small traces of the metal.

In section 31, township 48, range 17 west, and section 36, township 48, range 18 west, there occurs a belt of quartz veins. They vary in direction and lack in continuity; they occur as a succession of strings and bands, corresponding quite closely in position with the foliation of

the rock. Rarely in the vicinity of the veins the quartzite schists seem to be greatly shattered and recemented, thus having the appearance of a breccia.

In such localities the quartz is generally associated with siderite, when fresh, and with a spongy, rusty condition when weathered. This rusted, porous condition extends in places into the schist for many feet. It gives evidence of the earlier presence of some accessory mineral, probably iron-carbonate. It occurs in zones of well defined distribution.

Moose River Valley

MAHTOWA EXPOSURES

Around Mahtowa are several exposures of the quartzite-schists stretching westward from the Blackhoof valley. In section 5, township 47, range 18, is a ledge of rather massive rock, with schistose structure locally developed. The slaty cleavage characteristic at Thomson and Cloquet is lacking. The rock breaks coarsely, and carries evidence of much pyrite or iron carbonate below its zone of weathering in the cubical and rhombohedral cavities so frequently seen.

Pressure has resulted in a folding, quite clearly shown in some hand specimens. Wells give evidence of wide distribution of these rocks slightly below the surface.

BARNUM EXPOSURES

The schists are widely exposed over miles of almost level surface around Barnum. At the railway depot there is some contortion, a gentle dip southward, an alternation of foliated and quartzose phases, a collection of quartz lenses, and an absence of slaty cleavage. The foliated is the dominant structure, and the southerly the dominant attitude of these rocks. Half a mile west of the station the rocks are more uniform, lithologically and structurally, and some quarrying has been done on that account. The dip southerly is slight, probably not over 5 to 10 degrees and interfoliated bands of glossy schist are only an inch or two thick at a maximum.

Northwest of the station, in section 15, township 47, range 19, there is an exposure in which a pyrite-bearing vein and diabase dike afford lithologic diversity. The badly weathered schists possess the same general characters as the rocks beside the railway. The locality is in the bank of a stream, and so covered that directions are difficult to determine with exactness. The vein has been assayed for gold; a good trace was found.

The dike is badly weathered. Its texture is medium, and composition appears uniform: a basaltic structure is in the fresher portions, and a decidedly concentric weathering where greatest alteration is shown.

MOOSE LAKE EXPOSURES

Moose lake affords an exposure or two of some interest. Near the sawmills a railroad cut has been made to the depth of several feet in the clean gray schists. There is variation in texture from a mediumly coarse yet well defined schist to a slaty variety greenish gray in color and glossy in habit, yet lacking slaty cleavage. Bands of a few inches in thickness, consisting of calcium carbonate, occur in these glossy foliated rocks. The strike is north 70 degrees east, dip varying from 0 to 25 degrees toward the south 20 degrees east. Some contortion was noted. A dike of diabase porphyrite occurs in the west part of the town, cutting through the schists without modifying their rock-habit to any perceptible extent.

KETTLE RIVER SECTION

From section 21, township 46, range 20 west, to section 36, township 45, range 20, a distance of 10 miles, there is a most interesting series of exposures of hornblende-biotite schists. The rocks are very uniform in their structural characters and external lithologic habit. Layers of a decidedly quartzose habit alternate with the normal schist. With these are, more rarely, bands of a carbonate. At the northernmost exposure in section 21, township 46, range 20, there is exposed a wide vein of quartz regarded as the southwestward extension of the one outcropping in the Saint Louis river at Thomson and already mentioned. A mile and a half below this exposure the schists which lie in both banks of the river for a considerable distance are badly shattered and badly altered, so much so that they have been mapped by the Minnesota survey as Cambrian sandstone.* The strike of these rocks is very nearly east and west, varying perhaps to north 80 degrees to 85 degrees east, with a southerly dip, varying from 15 to 30 degrees.

Only half a mile from the locality just noted is an exposure 20 feet or more above the river, containing a notable per cent of graphite. It is situated 100 paces from the river; direction of strike, north 60 degrees east, magnetic, dipping south 30 degrees east, at an angle varying from 3 to 30 degrees. While the exposed area is not great, the indications in the black soil, widely distributed graphite chips and attitude of

* Geol. and Nat. Hist. Survey of Minnesota, final report, vol. iv, 1899, pl. 56.

rocks themselves are that there is a large area of graphitic shales. The percentage of carbon in these shales has not yet been determined.

The graphitic shales disappear, and at the first exposure southward the normal gray glossy schists come into view. There is some variation in the hardness and mineral proportion of the schists. The structure in places is somewhat massive, elsewhere decidedly schistose. The strike is north 60 degrees to 75 degrees east, with a southeasterly dip of 20 to 30 degrees, with local measurements as low as 15 degrees. Some little contortion is also seen.

In section 9, township 45, range 20, there are some interesting nodules. They are more crystalline than those around Mahtowa and at Thomson, approaching more nearly those seen at Little Falls and Moose lake.

The Kettle River section gives the most satisfactory place for securing an idea of the thickness of the formation that the entire region affords. The northernmost exposure along this stream lies in the northern part of section 16, township 46, range 20, and the southernmost, seen before the northward dipping schists are reached, lies in section 9, township 45, range 20. In this distance of nearly 6 miles, dip was measured at many places. Nowhere was it less than 15 degrees, and at several outcrops it was 30 degrees and more. In the entire distance there was seen no trace of displacement. The average attitude, therefore, can not give less than 2,500 feet per mile, which will thus make a total of 15,000 feet as the thickness of the schists of the Kettle River valley. This, it must be remembered, is without the top or the bottom of the series being seen.

The foregoing does not include the exposures from Stony brook southward to the Blackhoof valley. In this area a folding can easily be traced beneath the more prominent slaty cleavage. Owing to this, any measure of thickness is well-nigh impossible. A conservative estimate of the rocks in sight, taking into account folding, horizontal position, crushing, and other attitudes, is 5,000 feet. Added to the thickness seen in the successive exposures along the Kettle river, which, according to strike measured scores of times, are a continuation of the schists disappearing beneath the drift in the Blackhoof River valley, this gives a total of 20,000 feet as a conservative estimate of the thickness of the series under consideration. Farther westward, as has been shown, alteration, folding, and eruptive displacement preclude all possibility of reliable estimate.

Region west of Sturgeon Lake

At this point there is seen a decided change in the attitude and character of the rocks. The structure becomes sharply crystalline and in

places markedly fibrous with a decidedly hornblendic habit. Some narrow and unobtrusive veins appear, carrying pyritous contents. The most conspicuous veins, however, are the white quartz. The veins vary from a foot or two in thickness to paper thinness, are quite irregular in direction, locally are considerably contorted, as a rule free from pyritous or other metallic accessories, and very frequently assume a lenticular aspect, when are found quite liberal proportions of coarsely crystalline feldspathic content.

The strike of this group of rocks shows some variation. Along the road between sections 19 and 30 the strike of the foliation is north 80 degrees east, with a dip of the laminæ partly south and partly north. Passing south of the road 200 paces, and the strike is north 70 degrees east and the dip 80 degrees north; 200 paces north of the road the strike appeared to be north 65 degrees east and the dip 75 degrees north. The rock at this point is more coarsely crystalline than elsewhere. An abundance of garnets is present, strongly suggestive of contact alteration. The rather small crystals are of the ordinary variety.

Farther south, in section 30, township 45, range 20, the rock is more finely crystalline than to the north, and exhibits some variety of texture and color. Instead of the dark green, so dark as to appear black to the eye, the rock has a pea-green color in many of its bands. The direction is nearly east and west. This determines the direction of the ridges which stretch across these sections. The hornblendic rock is locally so fibrous that slender pieces 6 to 7 feet long are seen lying about. The strike over all these long parallel hillocks is nearly the same, and the dip varies from vertical to north 40 degrees.

Through section 25, extending nearly north and south, is a creek valley. At present it is little more than a long narrow marsh, yet its walls, its width, and depth suggest at an earlier date a much larger stream. It may be an old channel of glacial origin. The seeping water at present moves northward, but at the time of its cutting very likely a large stream flowed toward the south. Its nearly vertical walls, from 20 feet to 40 feet high, show interesting structure lines, joints, folia, possible bedding planes, and other phenomena. The valley exhibits all of the characters of an abandoned valley of erosion.

The most interesting lithologic feature of this locality is the presence of several exposures of limestone. This rock, approached from the north, is disclosed by the fragments which lie in the bed of the stream. The most northerly exposure of the rock in place is in the east half of section 25, township 45, range 21 west. It lies 8 to 10 feet in thickness, dipping southward at about 20 degrees. The rock is rather fine grained and thoroughly crystalline. Its color is a light pink with a faintly trans-

lucent habit. Along the east wall of the valley of erosion which unites with Birch creek, only a few paces from the first exposure just described, are several other spots where the limestone outcrops, but nowhere is such clear, evenly crystalline material. It is, instead, at the surface a crumbling mixture of quartz and carbonate, so as to be a quartzose limestone of quite variable composition. This rock is so easily decomposed, and the beds thereby become so overshadowed, as it were, by the more enduring hornblende schist with which it seems to be interstratified, that the structural relations are difficult to discover. It is quite probable that the valley along whose walls these exposures occur has been formed because of the presence of a rock thus easily eroded.

Several miles to the west of Rutledge, in section 30, township 44, range 21 west, are masses of gneissic rock protruding from the otherwise universal sheet of glacial drift. Coursing through these rocks in various directions and at various angles of inclination are dikes of granite. These dikes are narrow, yet varying in width. Structurally, they are pegmatitic; mineralogically, they consist of quartz, orthoclase, microcline, and plagioclase, with muscovite as the principal bisilicate constituent. The gneissic rocks are modified profoundly by acid intrusives, the most prominent result being a coarser texture, the presence of accessory garnets and pyrite, and the tendency to assume gneissic foliation.

Snake River Localities

Along Snake river, in township 42, range 23, through several sections, at intervals a more conspicuous occurrence of granitic dikes and inclosing schists is seen. At the log dam and sluice in section 9 occurs a most confused association of these rocks. A diabase dike several feet in width and of vertical position here breaks across the river. The schists are biotite muscovite of a mediumly coarse texture, not only strongly schistose, but even clearly foliated. The muscovite is locally well crystallized and again segregated into nests of radiating individuals, pinnately distributed along the fracture planes induced in the rock by this mineral.

The granite is usually gray, locally fine grained, but when in contact with the schists inclined to take on a pegmatitic habit having every appearance of coarse-grained granitic dikes. There are many veins and lenticular masses of quartz, some of them reaching a thickness of one foot or more. The jointing of these rocks is quite pronounced. The direction is vertical, and the joints stand from 4 to 10 feet apart. The remarkably zigzag character of the channel, as the river cuts its way through walls nearly vertical and 15 feet high, is apparently due to the

strength of this jointing and the success of the river in following these lines of least resistance as it carved its bed in the fresh crystalline rocks.

Rum River Valley

Along the Ann and upper Rum rivers, including some hitherto undescribed localities around the east side of lake Mille Lacs, are many exposures of a medium grained hornblende biotite granite with no visible areas of schists. There are two types of granitic rocks: one red and somewhat coarse grained, seen along the west branch of the Rum river and its tributaries; and the other light gray and medium grained, characteristic of the Ann river valley. There are representatives of the two granite types, the red and the light gray, found in the region intervening between the Kettle river on the east and the Mississippi on the west, comprising several thousand square miles in the very center of the state. These Rum River and Snake River outcrops would seem to be along the eastern border of the granitic area, where the exposures disclose a series of dikes breaking into and markedly modifying the older schists which stretch southwestward from the graywacke beds of the Thomson district.

Morrison County

Northwestward from the foregoing, between lake Mille Lacs and the Mississippi river, at the mouth of the Elk, are many exposures of granites and gneisses. At the Mississippi itself are extensive areas of hornblende-biotite schists carrying garnets and staurolite in profusion. At the large reef below the mouth of the tributary Swan river a bed of rather fine grained pink limestone was reported several years ago. The accounts would seem to make it identical with the limestone exposed southwest of Sturgeon lake. If this surmise be correct, the two localities have between them many intrusions of granitic eruptives. At Little Falls and westward are intrusions of basic rocks, both diabase and gabbro. Extensive exposures of biotitic olivine gabbro occur in section 13, township 129, range 30 west, and in a succession of outcrops southward far into Stearns county. In the northwestern corner of Morrison county altered schists occur striking westward and standing nearly vertical. In their alteration much calcium carbonate has been formed, which at the present time constitutes a considerable bulk-percentage of the schists. Beyond Morrison county northwestward the schists have not been seen. Eruptives, both acidic and basic, are exposed; the former as epidote granites at Ashley, Ward, and in southwestern Cass county; the latter, besides several diabase dikes at several localities, in an area of interesting apatite-diorite at the mouth of Fish Trap brook. Northward of the

Morrison County exposures, glacial drift covers the schists, as remarked in the mention of the Brainard deep well (*ante*, page 345).

Taken as a whole, Morrison county, in its content of rock types among the ancient crystallines, is among the most diversified areas of the state. The range of granitic rocks represents several varieties, and gneisses in the eastern part of the county are important. Gabbros, diorites, and diabases appear in unexpected force to the west of the Mississippi river. Finally extensive belts of hornblende-biotite schists are seen to cross the course of the river, locally loaded with staurolitic crystals and garnets, while in the more disturbed areas lenses of a peculiar hornblendic quartzose habit appear, of sufficient lithologic interest to receive the name quartz-diorite from Doctor Kloos.

Granite Areas

Throughout a large area in Benton, Sherburne, and Stearns counties the rocks are, so far as seen, wholly granitic. There is considerable variation in texture, color, and chemical composition. An acidic type prevails, represented by the Le Sauk granites, with 74 per cent of SiO_2. A heavy proportion of quartz is in such varieties. Again the per cent of SiO_2 sinks nearly to 69 per cent. Here the proportion of quartz is small and the color prevailingly dark. These characters correspond with a heavy proportion of hornblende as the bisilicate constituent.

A discussion of these granite areas is without the scope of this paper. Their presence along the Mississippi is mentioned chiefly to enforce the westward extension of the area believed to be Keewatin, which stretches from the city of Duluth southwestward even beyond the central portions of the state.

Lithology of the Series

THE PROBLEM PRESENTED

The effort is made in the following pages to trace a petrographic and genetic relationship between the carbonate schists, graywackes, and graywacke slates of Thomson, Carlton, and Cloquet, and the thoroughly crystalline dolomite, biotite, and hornblende-biotite schists as represented along the Mississippi, Snake, and Kettle rivers, in the several localities enumerated on the preceding pages. Such a relationship is not infrequent in this part of the continent.

OTHER LOCALITIES CITED

Fifteen years ago Van Hise* traced out and established the relation-

*C. R. Van Hise: Upon the origin of the mica-schists and black mica-slates of the Penokee Gogebic iron-bearing series, Amer. Jour. Sci., vol. xxxi, 1886, pp. 453–459.

ship between (1) well defined graywackes and graywacke-slates, (2) biotitic graywackes, (3) biotite-schists and muscovitic biotite-schist of the Penokee-Gogebic range as a graded series from the slightly altered graywackes to the crystalline mica-schists, this relationship being formulated in the following proposition:

"the result being the production from a completely fragmental rock, by metasomatic changes only, of a rock which presents every appearance of complete original crystallization, and which would be ordinarily classed as a genuine crystalline schist." *

At nearly the same time Lawson worked out the relationship between the clastics and schists of the Rainy Lake and Lake of the Woods region and stated his results,† showing that the granite of the region is of later origin than the folded schists, and that the period of folding occurred at a date earlier than that of the deposition of the typical Huronian of Logan—that is, the Animikie.‡

Two years later Lawson,§ in stating the results of his studies around Rainy lake, says with reference to one particular locality, that the detrital origin of the series of fissile soft green chloritic and hornblendic schists is established through their forming the paste of a pebble-and-boulder conglomerate (page 83 F), and touching another locality he says (page 84 F) that the matrix of a conglomerate is a more or less calcareous, decomposed schist.

Again, in the Black hills of South Dakota, a region to be associated genetically with that extending from lake Superior southwestward, within which lies the district under discussion, Van Hise observed || that slates, quartzites, and conglomerates occurring in a broad central belt become more crystalline and grade into schists about the volcanics to the north and the granite of Harney peak to the south. "In the transition in both directions, graywacke-slates change into mica-slates, the mica-slates into non-foliated mica-schists, the non-mica-schists into foliated mica-schists (which are both garnetiferous and staurolitic) and even into gneisses."

HISTORICAL NOTES

The group of rocks around Thomson and Carlton, as has already been stated, have long been considered clastics in origin. In a vague sort of

* Loc. cit., p. 454.

† A. C. Lawson: Report on the Geology of the Lake of the Woods, Ann. Rept. Geol. and Nat. Hist. Survey of Canada, 1886, pp. 1-151cc.

‡ Loc. cit., p. 13.

§ Geol. and Nat. Hist. Survey of Canada, Ann. Rept., new series, vol. iii, pt. i, report F, pp. 1-190.

|| C. R. Van Hise: The pre-Cambrian rocks of the Black hills, Bull. Geol. Soc. Am., vol. i, 1890, pp. 203-243. Quotation is from p. 223.

way the rocks at Little Falls have been regarded as stratigraphically related to the "Thomson slates." No evidence has been adduced, either in their structural or mineralogic relations, to confirm this view. Again, the granites at Saint Cloud, Sauk Rapids, and Watab have been held to be Archean, and it was assumed further that could a contact be found beneath the drift, it would disclose the Little Falls "slates" as lying unconformably on the granites. The granites of the Saint Cloud area were held to be of the same age as the gneisses and gabbro schists of the Minnesota River valley. It was also thought that the Keweenawan eruptives at Chengwatana, Taylors Falls, and other places were poured out and spread over the slates and schists as lavas cover older rocks in every other region, and that the Cambrian sandstones stretched through the upper Mississippi River valley northward until the worn edges of all the underlying pre-Cambrian formations were covered by them over thousands of square miles, into the very heart of the Lake Superior synclinal trough.

THE GRAYWACKES

These rocks occur around Thomson, Carlton, and Cloquet in extensive exposures, typical in the village of Thomson. Their prevailing color is a dark gray, which on weathering fades almost to white. The variation in mineral composition is clearly evidenced on the weathered surfaces. The rocks are everywhere shattered and fractured through crustal movements until it is practically impossible to quarry blocks of satisfactory size. Even the slates are so fractured and warped that only three or four localities in the entire district have been found where plates of sufficient size for commercial purposes can be extracted. Plate 32, figure 1, shows this shattered condition near the railroad depot at Thomson, where glaciation has smoothed the hardened graywacke surface. Here the quartz, resisting corrosion, stands out in rounded or etched grains, while numberless pits which the surface carries represent the former resting places of the more easily decomposed carbonate and silicate constituents. The grains vary greatly in size; the largest are the size of marrowfat peas, the others diminishing until a texture of slaty fineness is attained. As a rule, the finer the texture the darker the color, the slates being very black. The rock is thoroughly indurated. It has a harsh feel when broken across the planes of foliation. The individual grains are so cemented that a conchoidal fracture and non-granular habit characterize the more massive beds. The thickness of these beds could not be measured, outcrops showing from 50 to 100 feet each; hence the total must reach thousands of feet.

In mineral content, the coarser varieties, or the graywacke proper,

contain quartz in large proportion. The grains are largely multigranular—that is, worn down from granitic quartz—and partly unigranular. Feldspar in two or three varieties is frequently seen; so, too, are particles of fine black slate and rounded pebbles of an ancient diabase. That the feldspars result from the degradation of granitic rocks rather than basic eruptives is indicated by their albitic rather than anorthitic habit. Microcline is a less frequent, yet by no means rare constituent, while orthoclase was proved in only two or three instances.

FIGURE 1.—*A Grain of Albite Feldspar.*

The albite feldspar is corroded and changing into a finely granular uniaxial material. To the right the feldspar is almost wholly altered. From slide 1053, from one of the freshest specimens of graywacke taken at Thomson.

Microscopically quartz appears in even greater proportion than macroscopically. A considerable proportion of the matrix binding the coarser grains is finely crystalline quartz, bearing every evidence of secondary origin. Again, it is the result of alteration *in situ*. The rule of distribution is, the more altered the rock the more finely crystalline, proportionally, is quartz seen to be. The original grains of this mineral can usually be distinguished from the secondary by the frequent occurrence

in the former of rutile needles, bands of liquid or empty inclusions, a wavy extinction, and other quite general characters. Hornblende is present as a secondary constituent, distributed in fibrous individuals within the matrix enveloping and gradually absorbing the clastic grains, both fine and coarse.

The feldspars are next to command interest. Rarely are the individual grains of their original size and contour. The outline is not sharp and smooth as one would expect in a rounded grain, but the contact line shows a finely crystalline interlocking of several mineral species. A slight kaolinization characterizes the freshest feldspars, and this increases with the degree of alteration undergone. Complete replacement has undoubtedly taken place in some of the feldspars. Figure 1 shows their usually partially altered condition. The grain is still present in spots and lines which lie with considerable regularity of direction. The finely crystalline alteration product in this case is a uniaxial mineral and is thought to be siderite.

The matrix now binding these grains of quartz, feldspars, and less frequent rock and mineral fragments together is very finely crystalline. It consists largely of quartz, yet partly of hornblende, biotite, and kaolinic and chloritic minerals. In origin it is largely interstitial deposited as independent particles. Its source is doubtless within the rock mass itself and for the most part in the corroded grains of quartz, feldspar, and other more easily soluble silicates. Not all the matrix material is secondary, since naturally many fine grains of the constituent minerals were sifted in among the larger ones as the rock was laid down.

The quartz and feldspar fragments even in the least altered sections show no clear traces of secondary growths. In this respect they differ from these same mineral grains in the Penokee-Gogebic range as described by Van Hise.*

THE GRAYWACKE SLATES

The most conspicuous difference between these rocks and those just described is that of texture. The gradation from the coarsest graywackes to the fine and often glossy graywacke slates is difficult to follow because so imperceptible. There is nowhere any sharp line of separation. Even where the division can be located within a band 2 or 3 inches wide the line is still indistinct. The actual separation is to be sought for in the texture of the sediments out of which these rocks have been developed. The deposits were alternatingly coarse and fine. Where coarse, the graywackes have come down, and where fine, the graywacke slates occur in increasing fineness until the clay slates, which have been quarried in

* Loc. cit., p. 456.

several places around Thomson and Cloquet, represent the existing alteration stage.

THE CLAY SLATES

These are extremely finely crystalline rocks occurring in bands from 2 or 3 to many feet in thickness between the layers of graywacke and graywacke slate. The difference between the clay slates and those apparently lies in the effect which pressure and shearing have left upon them. The slates have a well defined cleavage, so complete that considerable quarrying has been done, while the graywackes have a typical schistosity, the more perfect as the rocks are more thoroughly altered. The two are seen side by side in many situations, as plate 31, figures 1 and 2, clearly shows.

The texture of the clay slates is so extremely fine that the mineral composition cannot satisfactorily be determined. In comparison with the commercial product of the Slatington quarries of Pennsylvania, no marked difference was seen. Series of slides made from the ordinary roofing slates of Thomson and Cloquet and from the graywacke series gathered at different points within this district gave texture the chief distinction to be made. The fundamental difference is no doubt one of chemical composition, brought about by the variation in the size of grain and consequent transportation at the time sediments were depositing. The transverse cleavage characterizing the slates is due to movements produced by lateral compression. This force has been sufficient to produce the cleavage phenomenon in the fine sediments through their capacity for microscopic faulting, and to place in vertical direction the carbonate concretions which occur both in slates and associated graywackes (see plate 31, figure 2).

THE HORNBLENDE GRAYWACKES

These rocks differ from the foregoing graywackes in the extent to which alteration has progressed. Quartz which appeared in those as well preserved rounded grains here has to a large degree passed into a microcrystalline stage. Feldspars appear in rare and isolated fragments and in areas of finely crystalline alteration products, namely, quartz, calcite, siderite, muscovite, and hornblende. The figure selected for illustrating this phase of the alteration is one in which hornblende is developing a large area in crystallographic continuity out of what are regarded as grains of feldspar and quartz. Numerous globular dark grains, identified as magnetite, are scattered through the secondary portions of the field. More rarely than in the preceding are seen fragments of the earlier rocks out of whose degradation these hornblende gray-

wackes were formed. It is to be noted that the secondary minerals are in much smaller individuals than those from which they were derived (see figure 2), where hornblende is developing as a secondary product in the metamorphism of these rocks.

THE HORNBLENDE SCHISTS

These rocks are regarded as the accomplishment of the processes of rock and mineral alteration acting on the graywackes. A perfectly crystalline hornblende-schist is the abundant rock in the region west of Moose lake and Sturgeon lake. While hornblende occurs in the freshest

FIGURE 2.—*Hornblende Graywacke.*

The original grains of hornblende graywacke have almost completely disappeared. This figure shows hornblende developing in crystallographic continuity with larger areas of hornblende, also doubtless secondary, developed from original graywacke grains. 1, quartz, 2, hornblende; 3, feldspar. Banded portions, new hornblende.

graywackes of Thomson and Carlton as an interstitial mineral, in the region just named it has developed into the dominant rock constituent, placing even quartz in the background. The parallel position of the grains is usually seen, and the individuals elongated parallel to the axis *c*. Quartz is present in clear, well defined grains, bearing every indication of being secondary. Garnets and magnetite grains are rather numerous. It was observed that toward the surface at every exposure there was a greater proportion of biotite than at a few inches within the

rock, a suggestion leading to the belief that the biotite schists of the district are secondary after the hornblende rocks. There is not the slightest trace of remnants to demonstrate an earlier condition; hence stratigraphic relationships and lithologic condition are the data accepted in the interpretation given of the stages of alteration leading up to the existing completed schists.

The most marked macroscopic feature of these rocks is the uniformly schistose structure. Locally this is varied by the occurrence of more or less contorted veins and sharply lenticular masses of white quartz. Often associated with these are segregations of pink orthoclase, and more

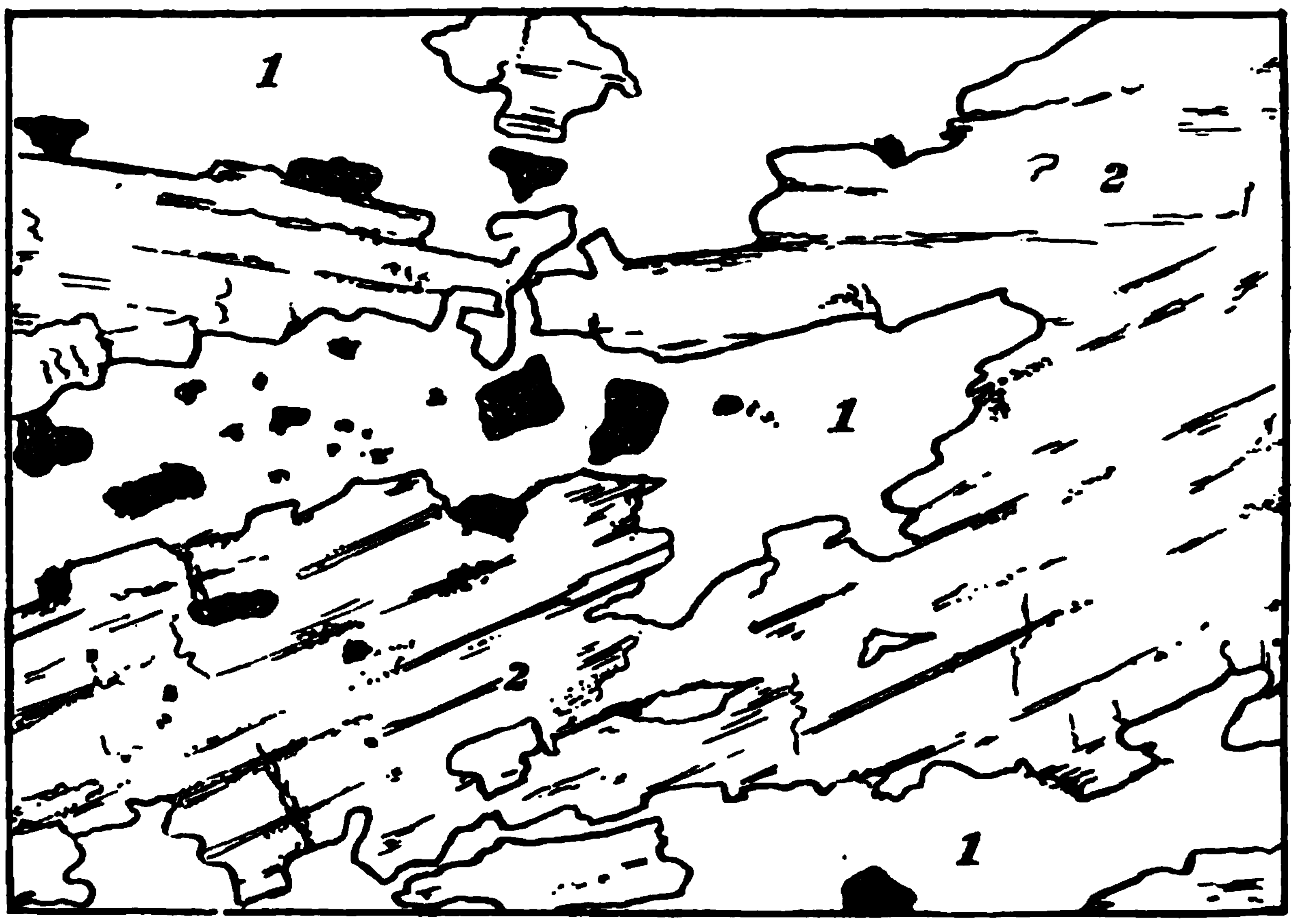


FIGURE 3.—*Hornblende Schists.*

The original clastic grains have entirely disappeared, and no trace is seen of the original condition of the rock. Hornblende quartz and magnetite are the minerals recognized. 1, areas of quartz; 2, hornblende.

rarely the dioritic lenses first noted by Kloos * at Little Falls, and since seen at many localities within the district. Very generally in these more altered phases garnets are abundant. They are especially numerous in those belts containing the lenticular masses of white quartz. At the log dam on Snake river, where the schists are greatly shattered by granite dikes, the texture is coarse.

Microscopically the quartz is in clear, perfectly transparent grains carrying few impurities, as minute crystals of hornblende and magne-

* J. H. Kloos: Neues Jahrbuch für Mineralogie und Petrefactenkunde, 1877, p. 36.

tite. The hornblende is in strongly pleochroic plates, with prismatic habit and generally parallel position. Figure 3 is from a representative hand specimen. Magnetite is present. Frequently its sections are quadratic, and they are strewn through every other mineral part of the section. Garnets show the usual tendency toward absorbing quartz in their growth to a considerable proportion of their bulk. Other minerals are rare. Staurolite appears farther westward as an important accessory.

THE HORNBLENDE-BIOTITE SCHISTS

These rocks differ in only a slight degree from the hornblende-schists just discussed. They carry biotite in addition to the minerals named in the preceding rock, are quite fresh looking in normal phases, and their texture is so fine that it is difficult to distinguish them from those carrying only hornblende as the bisilicate constituent. As a rule, the hornblende folia are very minute compared with the biotite. There are but few accessory minerals, garnet being the most conspicuous, while, microscopically, magnetite appears.

These rocks have every appearance of having resulted from the alteration of the hornblende schists. It must be admitted, however, that the evidence that such alteration actually occurred is incomplete. Specimens were not secured in sufficient quantity and from crucial points to establish the series or demonstrate the genetic relationship. In intermediate phases traces of the earlier constituents can be seen. Veins are frequent in these rocks. Their contents are made up partly of enlargements of the neighboring broken mineral grains, and thus point to the alteration processes as in progress.

THE BIOTITE SCHISTS

These rocks occur in several localities. In general field characters they are indistinguishable from the partially altered graywackes or the hornblende graywackes already described. The freshest phases show hornblende in small proportion; normally they carry biotite as the almost exclusive bisilicate constituent. Garnets are a characteristic feature of the entire series of rocks which have resulted through the complete alteration from the graywackes. In the biotite schists the garnets are altering into serpentinous products; some crystals having entirely disappeared, the resultant product, as a finely crystalline mass, presents the optical reactions of serpentine.

THE STAUROLITIC BIOTITE SCHISTS

These biotite-bearing rocks are characteristic along the Mississippi river for about 10 miles north and south of Little Falls. The strike is

north 10 to 30 degrees east, thus showing a strong deflection southward from the general direction around Carlton and along the Kettle river and its tributaries. The dip in places is northwestward—70 degrees at Swan river, 65 degrees at Muncys rapids, 70 to 75 degrees at Pike rapids, very nearly vertical at Little Falls, and finally, at the mouth of Little Elk river, the most northerly point where exposed, the dip varies from vertical to 80 degrees southeast, while the strike is north 40 degrees east, a notable variation from that at Little Falls. Quartz veins usually only an inch or two in width, lenticular masses of "quartz diorite," the occurrence locally of numerous staurolitic crystals from a half inch to two inches long, with numerous garnets occasionally filling the matrix, are the chief structural characters of interest. It is to be noted that these are characters peculiar to contact phenomena. Microscopically the typical rock is a biotite schist. A specimen from Pike rapids, one of the finest exposures on the Mississippi river, shows a groundmass of finely crystalline quartz grains with much coarser folia of biotite plentifully distributed. Crystals of staurolite and garnet are numerous, the former up to an inch in length scarcely differentiated from the quartz of the groundmass of the rock, while the light pink garnets are also full of quartzose inclusions. They seem to have rejected every other mineral save quartz in their crystallization. At the surface the biotite has undergone that physical change which in reflected light results in the lustrous golden yellow color so frequently observed in decaying drift boulders, namely, the deposition on the cleavage folia of films of iron oxide.

THE LIMESTONES

These rocks offer a wide range of varietal characters. In the creek to the north of the high exposures of fibrous hornblende schist southwest of Sturgeon lake, the limestone is remarkably free from mineral impurities. The texture is fine, color a clear, delicate pink, and structural planes distinct. The other exposures are less clearly carbonates. Where the abandoned gorge occurs, the rock gives every evidence of profound alteration. The surface is disintegrating mingled silicious and calcareous material in which the residual is a mass of incoherent quartzose fragments. Beneath the surface the rock is firmer; within 3 or 4 feet it is quite coherent and appears to be a mass of quartz grains of clastic habit imbedded in a matrix of dolomite. The contortion seen in the rock is apparently due to alteration under great pressure with more or less shearing. There is ferric oxide enough in all these layers in which the carbonates occur to give the red color to the rock on exposure.

An analysis made by Mr Levi B. Pease, of the University of Minnesota, of the samples which, both to the unaided eye and under the

microscope, seemed to be freest from impurities, gave the following result:

	Per cent.
SiO_2	5.02
Al_2O_3	14.20
Fe_2O_3	2.00
$CaCO_3$	60.52
$MgCO_3$	19.11
	100.85

Farther to the north, in the midst of the graywacke slates, the hornblendic graywackes, and the hornblende schists, bands of carbonates occur, varying from a few inches to several feet in thickness. They show numerous grains of quartz intermingled with the limestone. In short, the same characters, save in color and degree of alteration, distinguish these bands as have been described for the thoroughly crystalline limestones near Sturgeon lake.

THE GRANITES

These rocks are chiefly of the hornblende-biotite type. In Morrison country a light gray biotitic, rather finely textured outcrop occurs. At the now abandoned site of Granite City an unusual hornblende gneiss occurs. Gneissic features occur along the Rum river. At two or three localities on Snake river interesting dikes of granite break through the schists and make them more coarsely crystalline.

For miles along the Mississippi river, past Watab, Sauk Rapids, and Saint Cloud, exposures of these granitic rocks abound. Of the hornblende-biotite type, they once were augitic rocks, for in the freshest exposures augite cores still remain in the midst of the clustered hornblende individuals, while, as the rule of distribution, biotite individuals form a circle outside the hornblende clusters.

THE DIABASES

The dike rocks, of which two or three varieties are included under the more generic term diabase, occur throughout the entire district under discussion. They present some local phases of interest, and show a considerable range of special characters. They can not here be described in detail. It may be said that, as a rule, they are of the porphyritic type. Feldspar is usually in lath-shaped individuals, lying within a groundmass of feebly reacting minerals, finely crystalline in texture and to a great extent altered from their original condition. The feldspars are in some instances, as in a dike in the railway cut south of Carlton, extremely fresh crystals of labradorite, and in others so far altered into

finely crystalline kaolinic material as to be almost indistinguishable. At Little Falls and Sauk Rapids olivine is seen in partially decomposed crystals. In these dikes olivine was once a very important constituent.

THE GABBRO

Gabbro is mentioned here because it occurs in Little Falls at the western end of profile V, plate 30, from Little Falls to Taylors Falls, across the southern and southwestern portions of the area under discussion, and mapped on plate 29. A belt of gabbro bosses stretches from Little Falls into the southern half of Stearns county. They are believed to be post-Keewatin. They are throughout quite similar in lithologic characters; hence the Little Falls outcrop may be taken as a type. This rock is a biotitic gabbro. Labradorite, diallage, possibly hypersthene, olivine, magnetite, and several alteration products derived particularly from the decomposing hypersthene and olivine, mark the mineral habit of the rock species. The texture is medium, and alteration is marked.

VEINS AND VEINSTUFFS

Around Thomson and Carlton, and similarly throughout the Saint Louis River district, there occur a large number of veins. Most of them are thin, and, save as they point to structural conditions, insignificant. They are plainly veins of infiltration wherever any direct clue to origin can be seen. In plate 32, figure 2, is seen a quartz vein from one to three inches in width, which is involved in the crumbling of the rocks to an unusual extent. In many of the microscopically narrow veins quartz is the leading constituent, through which hornblende needles are projected into the veinstuff from the edges of broken hornblende individuals. The process was one of enlargement of the hornblende grains through the attachment in crystallographic continuity of fibers extending the prismatic axes of the old and disrupted hornblende.

There frequently are to be seen the attachments of quartz crystals to the walls of the minute fissures, with their axial or *c* directions pointed across the space, not in crystallographic parallelism but rather in one general direction. As veins become broader, the arrangement of vein contents becomes more complex, until when feet across they are made up almost entirely of granular quartz, pegmatitic masses, intermingled siderite, and in one or two instances segregated sulphides. An example of the first named is seen at the bridge across the Saint Louis river at Thomson. It stands nearly perpendicular and strikes quite nearly with the slates through which it breaks. It conforms therefore in position with the slaty cleavage of the region. Yet it is far from regular. Its thickness varies, both horizontally and vertically.

This vein is cut by dikes, showing its relatively great age. It is believed to extend past Barnum and to reappear on Kettle river, where a similar quartz vein has been explored for gold west of Sturgeon lake.

In the Blackhoof valley are several interesting veins. Quartz is the dominant constituent still, but associated with it is siderite, somewhat coarsely crystalline, which alters easily, leaving a soft, hydrous oxide of iron. The siderite is not confined to veins, but is scattered extensively through the neighboring schists in crystals and crystal clusters, weathering easily, leaving the iron-rusted pits more or less thickly scattered through the rocks. There is usually a film of dark green to black talc like material enveloping the veinstuff and separating it from the rockmass.

West of Sturgeon lake there is an enormous number of quartz veins. They are of the lenticular and gash-vein type. The rock becomes thickly studded with garnets; its texture grows considerably coarser; the veins are not wide, a few inches being the greater thickness. They frequently anastomose in a very complex manner.

Passing farther southwestward into the central Minnesota area the veins are partly quartz and partly of the granitic type. The latter are locally pegmatitic, with coarse and well developed feldspar individuals imbedded in a matrix of hornblende and biotite, while elsewhere they are finely textured, possess a reddish color, and are highly silicious in composition.

The veins are thus noted because their lithology and distribution are closely associated with the petrographic characters of the rocks under discussion. They carry evidence which, taken in connection with other lines, confirms in the writer's mind the close genetic relationship of the entire series.

Age of the Series

Earlier Views

The age of these rocks has always been considered with reference to the occurrences at Thomson or where the staurolitic biotite schists cross the Mississippi river around Little Falls.

The Thomson series were regarded as Animikie, Upper Huronian, until Spurr announced in 1894, on what he regarded as sufficient evidence, his belief that they were at least as old as the Keewatin.* The grounds on which the earlier correlations were based were partly theoretic and partly lithologic. General composition and structural habit constituted the basis of determination.

When T. Sterry Hunt, in 1883, found the concretions of the slates and

*Amer. Jour. Sci., vol. 148, 1894, p. 162.

graywackes at Thomson, examination led him and J. W. Dawson to the conclusion that they must be evidence of keratose sponges.* That decision assigned the rocks containing them to an early Paleozoic terrane.

The geologists of the northwest for more than 20 years have held to the Huronian age of these rocks, using the term Huronian in its broad sense. This assignment has had as the strongest argument urged in its favor a general lithologic resemblance, reinforced by geographic situation. Spurr writes one paragraph in the history of correlation so well that he may be quoted in part:

"In the Third Annual Report of the United States Geological Survey, Irving† first hinted at the correlation of the 'Saint Louis slates' with the Animikie of northeastern Minnesota, as observed at that time around Gunflint lake and Thunder bay. He pointed out the general lithological resemblance between the two series and noted the difference in that the 'Saint Louis slates' are cleaved. In the same report, however, he‡ suggested the correlation of the uncleaved Animikie slates with the folded schists lying further north, and his descriptions and accompanying diagram clearly show that he included among these schists the larger part, if not the whole, of what we now know as Keewatin (Lower Huronian). In the Fifth Annual Report § he first confidently assigned to the Thomson (Saint Louis) series a place equivalent to that of the Animikie. . . . In the Seventh Annual Report ‖ he again refers to the Saint Louis slates as Animikie, and here first hints as to what horizon of the Huronian they were believed by him to belong—that is, the same as that of the upper slates of the Animikie series as represented by the Mesabi range." ¶

In the paper referred to (page 163) Spurr noted in the Virginia area of the Mesabi range a transition from the holocrystalline mica and hornblende schists, so pronounced in their habit in contact with the granites, to easily recognizable sedimentary and only slightly altered silicious and clay slates and graywackes at the most southward lying points where exposed, which are also most distant from the granite contact.

These Keewatin rocks, Spurr adds,** "possess a strongly marked regional cleavage or schistosity not far from vertical," trending north 70 degrees east. This east-northeast to west-southwest direction, with generally southward dip, it may here be emphasized, is a very common attitude of the Keewatin schists and slates from the gold-mining district north of Rainy lake to the southernmost exposures now known on the Snake river of east-central Minnesota, an air-line breadth of 200 miles.

---

* Transactions Royal Soc. Canada, vol. i, ser. iv, p. 250.

† Roland Duer Irving: Copper-bearing rocks of lake Superior. Monograph v, U. S. Geol. Survey, 1883, p. 162.

‡ Op. cit., p. 170.

§ Archean Formations of the Northwestern States, p. 196.

‖ Classification of Cambrian Formations, p. 422.

¶ Amer. Jour. Sci., vol. 148, pp. 160, 161.

** Ibid., p. 163.

Noting the characters of the less altered phases of the Virginia Keewatin, Spurr, on lithologic grounds, correlates these with the Cloquet rocks because almost every phase can be duplicated, the only difference being the presence in the latter of a minor transverse cleavage, while the resemblance of the Stony Brook exposures in section 27, township 51, range 19 west, and the Mesabi graywackes is complete.* Touching the staurolitic schists along the Mississippi river, usually regarded as the Thomson series changed by becoming crystalline, Spurr adds that they correspond exactly to the green schists and crystalline schists of the Mesabi district.

Turning to dynamic characteristics, Spurr says that one of the greatest differences between the least altered Keewatin near Virginia and the Mesabi (Animikie) slates is the steeply dipping cleavage in the former. This cleavage is for northeastern Minnesota a distinctly pre-Animikie character. It is seen in many localities within the Keewatin between Saganaga lake and lake Vermilion, and is a strongly imprinted character at Virginia, Stony Brook (lying 40 miles south), Cloquet, Carlton, and Thomson, and eastward into Duluth.

On the foregoing lithologic and structural grounds Spurr correlates the rocks around Carlton and Thomson with the Lower Huronian rather than with the Upper. With this correlation every geologist who, within the knowledge of the writer, has subsequently worked in this region has come into general accord.

THE PRESENT VIEW

The studies of recent years, as set forth in the foregoing summary of petrographic characters, have led the writer to the conviction that the basal rocks of the district described all belong to a single unit of geologic time. This unit or period was terminated by a series of volcanic disturbances resulting in extensive accumulations of granite in the Mississippi River region, a large number of granitic dikes in the district crossed by the Rum and Snake rivers, and a complete metamorphism of the vast series of silicious clastics along the Kettle River valley. The petrographic characters of the sedimentaries have been thereby so changed that no positive recognition of their clastic character is to be seen until Mahtowa and Carlton are approached as one traverses the state from the Mississippi river toward Duluth.

It has been shown in the foregoing discussion that the rocks exhibit for some miles, in a succession of stages which can be followed step by step from Thomson southward, the graded alteration of coarse and fine graywackes into sharply crystalline hornblende and hornblende-biotite schists to the west of Sturgeon lake.

*Loc. cit., p. 165.

The observations of Spurr and his interpretation of them are accepted by the writer, inasmuch as the writer's own studies lead to the conclusion that the rocks from Cloquet to the exposures west of Sturgeon lake belong to the same series, which series, in the nomenclature of this paper, is designated Keewatin.

The schists, still followed for miles southwestward from Sturgeon lake, present no further variation than an intenser metamorphism would bring about, namely, the occurrence of a coarser texture, the introduction of quartz veins and lenses, and the presence of garnets, both minerals giving proof of great alteration, and the latter particularly an index of contact metamorphism, as in the Crystal Falls iron-bearing region,* and "due to the reactions between solutions passing between the intruded and intruding rocks and carrying dissolved salts from the one into the other."† In many localities, literature shows, garnets are a frequent contact mineral, and their presence and distribution are a guide in structural problems.

It is recognized that southwest of Sturgeon lake step-by-step determination of the rock- and time-continuity, so clearly traced from Stony brook to that point, can not be followed, owing to the covering of glacial drift, which leaves only occasional exposures in view. The rock relationship of these isolated exposures must for the present be a matter of opinion rather than actual demonstration. The opinion of the writer is that westward from Sturgeon lake to the Mississippi river and beyond the rocks are a continuation of the same Keewatin schists as occur in the Saint Louis and Kettle River valleys, broken, displaced, folded, and altered by crustal movements and the intrusion of the dikes, bosses, and laccolites of hornblende and hornblende-biotite granites. These granites have gradually replaced the schists, until in Benton, Sherburne, and Stearns counties not an exposure of the schists has yet been reported. Profile II, plate 30, shows this displacement.

This opinion is hesitatingly put forth, although it has been held by the writer for several years. Other discoveries are probable, and other rock formations may be brought to light. Archean knobs may be found protruding through the complex here assigned to the Keewatin. The local reasons for this assignment have been sufficiently dwelt upon, if not with convincing clearness or array of proof. Within any geologic region there are certain rock associations and relationships that, once recognized, are usually reliable. The observations in central and eastern Minnesota, on which the age relationships are herein based, are rein-

*Clements, Smyth, Bailey, and Van Hise: The Crystal Falls iron-bearing district of Michigan, etcetera. Monograph xxxvi, U. S. Geol. Survey, 1899, p. 415.

†Van Hise, Bagley, and Smyth: Marquette iron-bearing district of Michigan. Monograph xxviii, U. S. Geol. Survey, 1897, p. 514.

forced by the lithologic results already cited (*ante*, page 357), for the Penokee range, lake of the Woods, Rainy lake, Black hills, Virginia, Minnesota, and the personal observations of the writer along the northern boundary of Minnesota, where bosses of granite, dikes of the same rock, and diabase dikes break through the schists, which a few miles to the eastward give place to clastic rocks either through the waning strength of alteration processes or by superposition in identically the same manner as seen in this region under review.

The further proposition is proved: Much later than these events another period of volcanic activity occurred, in which basic eruptives in the form of dikes of diabase porphyry were intruded into the uplifted and eroded schists and acid eruptives, and a great fault line was developed which marked the line of weakness, defining the line of volcanic vents, out of which poured the enormous lava flows of the Chengwatana series of the Keweenawan.* No trace of these dikes has yet been found in the Cambrian.

Summary

Along the eastern border of Minnesota, and extending westward beyond the geographic center of the state, lies a belt of graywackes, schists, and both acid and basic eruptives. Around Thomson, Carlton, and Cloquet the rocks are chiefly graywackes and graywacke slates. Clay slates, carbonate schists, and diabase dikes are associated with them. Southward rocks occur which are plainly altered from the graywacke type just named. As shown by a very continuous series of exposures, these extend with practically no change in lithologic characters well into the Kettle River valley. Their attitude is practically without change—that is, they slope continually southward at an angle varying between 5 and 20 degrees until the district west of Sturgeon lake is reached. At this point the rocks are hornblende and hornblende-biotite schists carrying minerals of contact significance and interbedded with an interesting body of limestone which to a considerable extent is quartzose.

To the west of Sturgeon lake the attitude of the rocks is changed. Passing to the Snake River valley, schists occur gradually broken by granite dikes. From the Snake river westward to the Mississippi, granite becomes of growing importance until, west of the river, no known exposures of schist occur, the rocks being wholly hornblende-biotite granites, with which are associated dikes of diabase porphyry and bosses of biotitic gabbro.

The petrographic characters of the rocks are named. They correspond precisely with the stratigraphic and structural characters just stated in

* This Bulletin, *ante*, p. 327.

the interpretation they afford of the genesis and stratigraphic relations of the rocks under discussion. The regions named as affording similar petrographic conditions are the Black hills of South Dakota, Penokee-Gogebic iron range of Michigan-Wisconsin, the lake of the Woods, Rainy lake, the International boundary, and the Mesabi iron range at Virginia; which conditions point to these genetic states:

1. A period of sedimentation took place, during which mediumly coarse to fine silicious deposits were laid down over a large area and to a great thickness, estimated not less than 20,000 feet.

2. Following this came a period of volcanic activity, during which enormous quantities of hornblende-biotite granite, originally augitic acidic rocks, were poured out to the westward, probably contemporaneous with the granitic intrusions of the Mesabi range and Rainy lake. These intrusions faded out into a series of minor bosses and dikes to the eastward and in the central part of the area described.

3. Farther away from this center of volcanic activity the schistose condition of the sediments becomes less distinct until typical and slightly altered graywackes prevail.

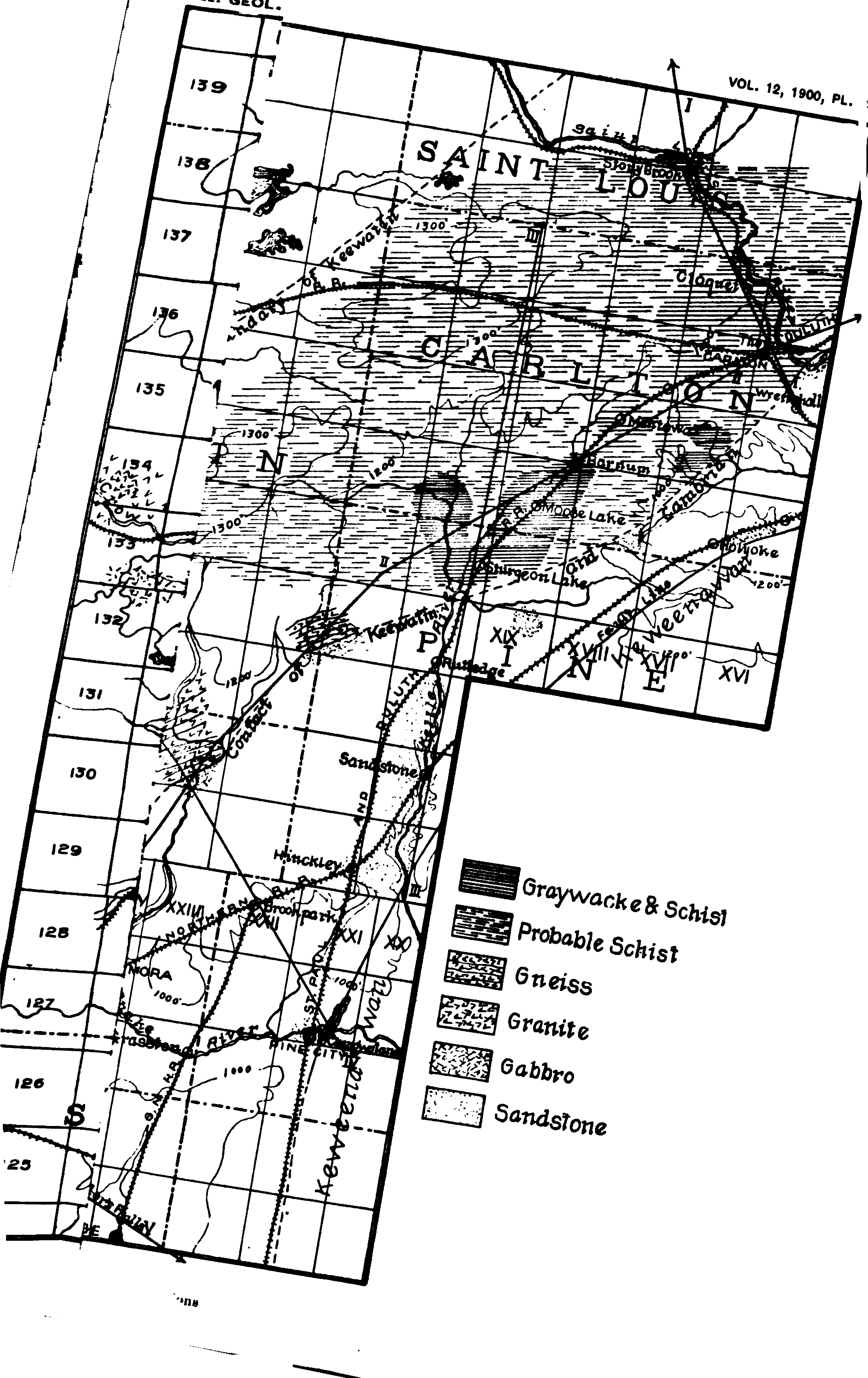
4. After an era of uplift and erosion, the entire area was subject to further volcanic invasion, when extensive dikes of diabasic rocks were forced into graywackes, schists, and granites alike; the southeastern edge of the intruded rocks was forced down by the development of a fault line and became covered with hundreds of feet of sandstone sediments, when the great Cambrian transgression of the sea took place.

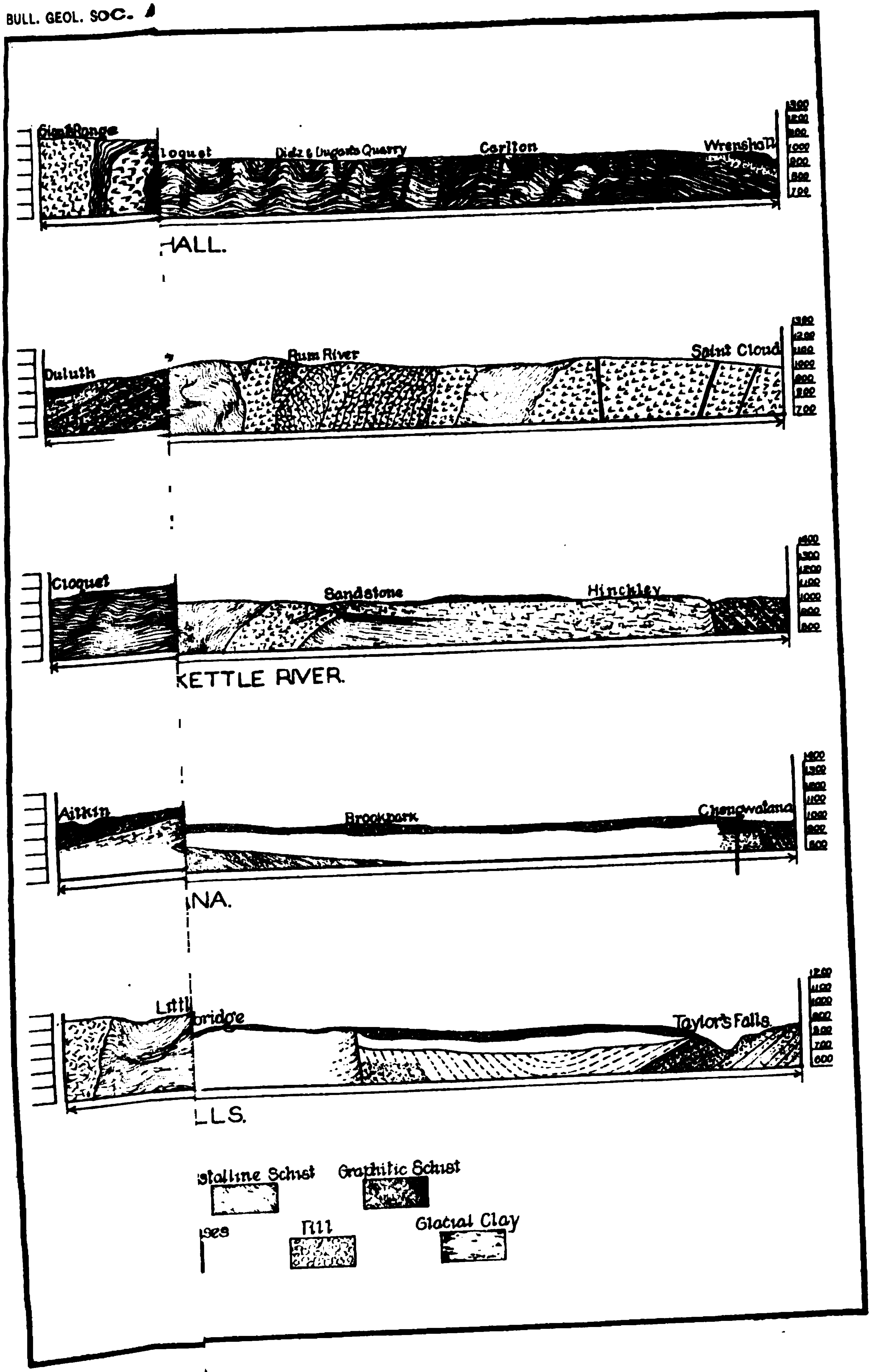
The age interpretation accepted for the rocks under discussion is that of Spurr, who regards the rocks along the Saint Louis river as Keewatin, basing his correlation on their relations, geographic, structural, and lithologic, to the Keewatin schists in the neighborhood of Virginia, on the Mesabi iron range.

The series along the Saint Louis river is shown to continue through the Blackhoof valley and into that of the Kettle river as far as the exposures west of Sturgeon lake as a series of finely crystalline hornblende and hornblende-biotite schists. These Blackhoof and Kettle River schists are therefore held to be of Keewatin age.

The rocks stretching southwestward from Sturgeon lake across Snake and Rum rivers into central Minnesota are, on account of their geographic continuation and lithologic and structural habit, assumed to be a continuation of the same schists as were followed from the Saint Louis into the Kettle River valley—that is, Keewatin.

If the investigations and opinions herein set forth prove in their general features to be correct, the eastern and central portions of Minnesota must be mapped as Algonkian rather than Archean, as has hitherto been done.


SAINT LOUIS
CARLTON
PINE
Cloquet
Thomson
Carlton
Barnum
Moose Lake
Sturgeon Lake
Holyoke
Rutledge
Sandstone
Hinckley
Brook park
NORA
PINE CITY
Contact of Keewatin
Keewatin
Keweenawan
Fond du Lac
Kettle River
Snake River
DULUTH
Graywacke & Schist
Probable Schist
Gneiss
Granite
Gabbro
Sandstone


Carlton
HALL.
Duluth
Rum River
Saint Cloud
Cloquet
Sandstone
Hinckley
KETTLE RIVER.
Aitkin
Brookpark
Chengwatana
NA.
Taylor's Falls
LLS.
Graphitic Schist
Till
Glacial Clay

Explanation of Plates

Plate 29.—*Map of Central-Eastern Minnesota*

On this map are represented all the rock exposures known. The conventional expresses the type of rock. The northern part of the map is probably Animikie; it is generally believed to be underlain by the southward stretching beds of the Mesabi iron range. The southeastward border is determined by the exposures of several localities and the deep well at Dalbo. The fault line defines the northwestward limits of the Keweenawan of eastern Minnesota. Topography from maps of Geological Survey of Minnesota.

Plate 30.—*Profiles across the Keewatin of Eastern Minnesota*

I.—Profile from the Giants range to Wrenshall.

This is a general section of the Mesabi Iron range (after J. E. Spurr), and the clastic series from Stony brook to Wrenshall. To the south of the Mesabi lies the series of more or less folded graywackes and associated rocks north and south through Cloquet and Carlton, where the rocks are in almost continuous exposure.

II.—Profile from Duluth to Saint Cloud.

The rocks are in exposure at all points named on the profile. A small area of Cambrian sandstone lies between the Snake River and Ann River crystallines.

III.—Profile from Cloquet to Hinckley along the Kettle river.

Beginning west of Cloquet the profile passes through the quarry-town of Sandstone to sections 22–23, township 41, range 20, where the great Keweenawan fault line lies. The Cambrian completely covers the underlying Algonkian rocks from Rutledge southwards.

IV.—Profile from Aitkin to Chengwatana.

The glacial Lake Aitkin clays are assumed to overlie the westward extension of the Mesabi, since to the southeast of Aitkin quartzite has been discovered. Cambrian sandstones exposed on the Snake river and penetrated to 700 feet at Pine City near Chengwatana are assumed to be continuous between these points.

V.—Profile from Little Falls to Taylors Falls.

To the east of Dalbo this profile passes outside the area mapped.

All of these profiles are partly generalized.

PLATE 31.—*Slate Quarry and Graywacke Exposure*

FIGURE 1.—Slate quarry at Thomson, Minnesota.

The slate dips strongly southward. The diagonal lines across the face of the quarry represent the bedding planes. Lenticular nodules of sideritic material lying along these lines have assumed a vertical position conforming with the slaty cleavage. This cleavage can be seen on the left of the picture above the hammer. Photograph by C. P. Berkey.

FIGURE 2.—Shattered surface of graywacke and graywacke slate, Thomson, Minnesota.

The dip is southward. In these rocks also the carbonate nodules have been squeezed into a vertical position. These are well shown on the knob to the right. Near the middle of the picture is a finely carved glacial groove whose wearing is in the direction of the bedding of the rocks. Photograph by C. P. Berkey.

PLATE 32.—*Graywacke Slate and Graywacke*

FIGURE 1.—Exposed surface of graywacke and graywacke slate near Thomson, Minnesota.

The rock is thoroughly jointed, and occasionally some displacement is seen. This fracturing was probably produced coincident with the production of the slaty cleavage seen in neighboring clay slates. Surface produced by glaciation. Photograph by C. P. Berkey.

FIGURE 2.—Graywacke with contorted quartz vein, Carlton. Minnesota.

This view is from the railroad cut south of Carlton, Minnesota, and shows a greatly contorted quartz vein one to three inches wide. The graywacke is quite compact and free from the sideritic nodules characteristic of the exposures at Thomson, as shown on the preceding plate. Photograph by C. P. Berkey.

Figure 1.—Exposed Surface of Graywacke and Graywacke Slate near Thomson, Minnesota

Figure 2.—Graywacke with Contorted Quartz Vein, Carlton, Minnesota

GRAYWACKE SLATE AND GRAYWACKE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 377-394, PLS. 33-34 SEPTEMBER 4, 1901

GEOLOGY OF RIGAUD MOUNTAIN, CANADA

BY OSMOND EDGAR LE ROY*

(*Read before the Society December 28, 1900*)

CONTENTS

INTRODUCTION

Rigaud mountain is situated in the northwestern part of the county of Vaudreuil, Province of Quebec, Canada, and includes in its area the parish of Saint George and parts of the parishes of Rigaud, Saint Redempteur, and Sainte Marthe. It is the most western of a line of hills of igneous origin, which, in the vicinity of Montreal, forms the principal topographic feature of the eastern part of the Paleozoic plain of central Canada. These hills—locally termed mountains—are at no great distance from the border of the V-shaped Laurentian protaxis, and follow a line of disturbance which is almost at right angles to the trend of the Notre Dame range. In westward succession there are Shefford, Yamaska,

* Introduced by F. D. Adams.

Rougemont, Beloeil, Montarville, Mount Royal, and Rigaud. The hills of Brome, lying south of Shefford, and mount Johnson, south of Beloeil, are on another line, but evidently belong to the same series. Sir William Logan has described them as being of post-Silurian age, and from the field relations of those recently examined such has been found to be the case, with the exception of Rigaud, whose age is doubtful, owing to the fact that the contact between the Paleozoic and igneous rocks is wholly concealed by drift. In the absence, then, of any direct proof such as a contact would afford, it was thought by the writer that possibly the petrographical character of the rocks would show Rigaud to be closely related to the other hills. With this end in view, a detailed examination of Rigaud mountain was made, and the following pages contain the results of the field and laboratory work, together with the conclusions arrived at.

Topography

Rigaud, owing to the general levelness of the immediate surrounding country, occupies a more prominent position than its height would otherwise warrant. In shape the mountain is roughly oblong, and has an area of about 15 square miles. The topographic features closely resemble those of the neighboring Laurentian—rounded ridges and knobs of rock, partly bare, partly wooded, with drift-floored valleys of varying width between. The marginal area and some parts of the interior are well forested, otherwise the rock is exposed or only covered by a scrubby growth. In the west the mountain consists of a series of interrupted ridges, and longer axes of which have an east-and-west trend. The central part is rather plateau-like in character, and is made up of subordinate elevations of the roche moutonnée type, which exhibit in many instances stoss and lee slopes. On the line between Saint George and Sainte Marthe the plateau terminates in an abrupt slope to the south, and on this line the highest point of the mountain is situated, there attaining a height of 750 feet above sealevel. From this slope southward the area is but little higher than the immediate surrounding country. The eastern part is marked by one ridge, which is continuous throughout the width of the mountain, and runs in a northeast direction. The valleys between the plateau and principal ridges are comparatively broad, shallow depressions, well drained by intermittent creeks into the rivers à la Graisse and Racquette. They are floored with gravel, sand, and sandy loam, which in recent cuts show a very even stratification.

The most prominent ridge is the one fronting on the Ottawa river, the western part of which is shown in figure 1, plate 33. Its average elevation is about 550 feet, but attains at its peak a height of 704 feet above

FIGURE 1.—RIGAUD MOUNTAIN, WESTERN PART OF THE NORTHERN RIDGE

FIGURE 2.—MICROPHOTOGRAPH OF RIGAUD HORNBLENDE-SYENITE

Dark constituent is hornblende intergrown with feldspar in a graphic manner
Zonal alteration of hornblende also seen. Ordinary light × 44

RIGAUD MOUNTAIN AND HORNBLENDE-SYENITE

sealevel. The slope to the north is quite rugged, and many small precipices from 15 to 40 feet high have been developed, due to the ease with which the rock joints. The particular interest attached to this slope, however, is due to the occurrence of two large boulder deposits. One of these fills a depression just east of the peak, and tinged by local tradition is popularly known as the Devils garden. It is an irregular oval in form, with the longer axis running southwest, and occupies an area of about 50 acres. Higher parts of the mountain inclose it on all sides

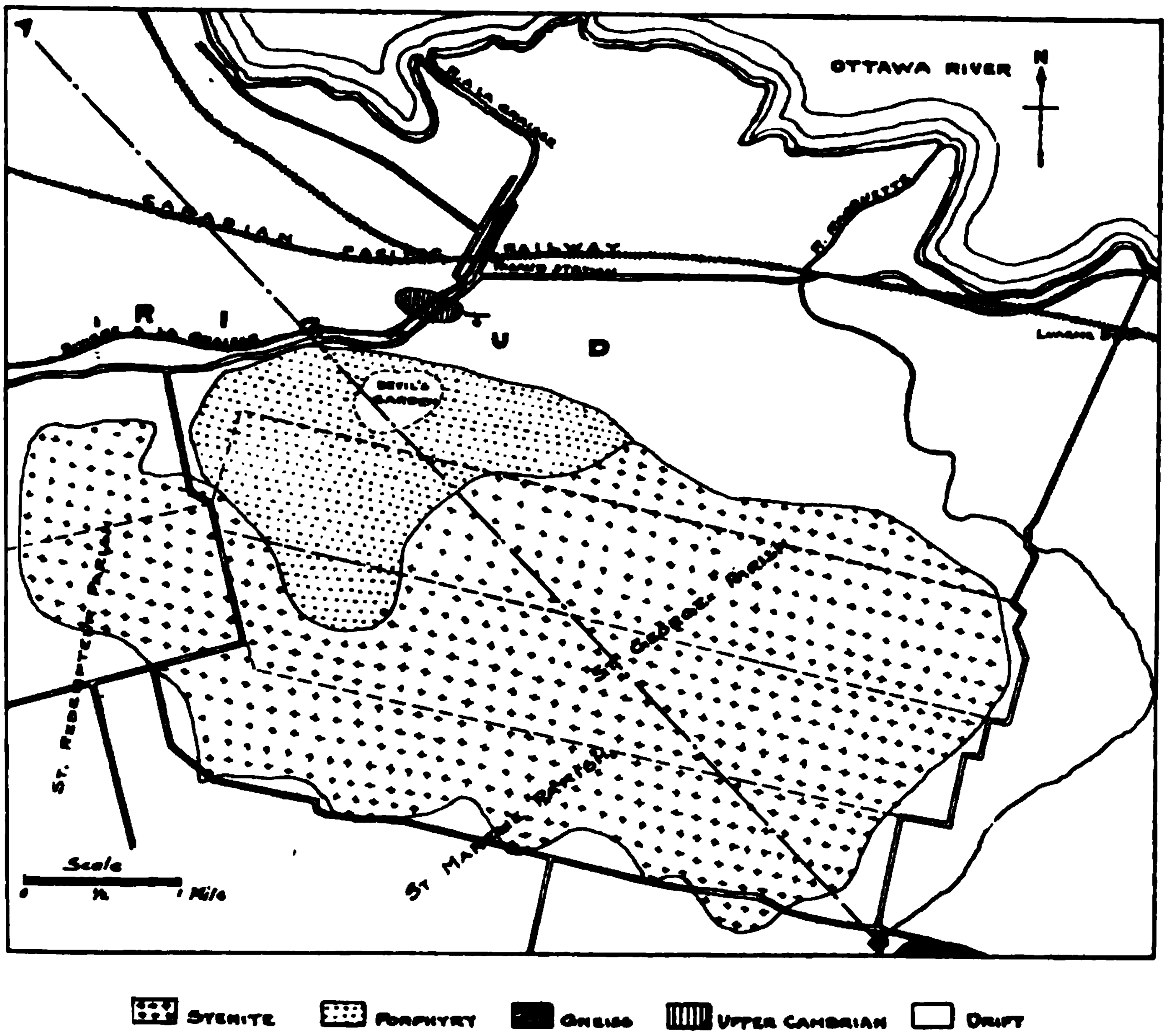


FIGURE 1.—*Map of Rigaud Mountain, Canada.*

except the northern, which is lower, especially in the northeast, where the deposit terminates in a rather abrupt fall of about 20 feet. The boulders are subangular or well rounded, from 5 to 20 inches in diameter, and are arranged in a series of parallel ridges which run in a direction at right angles to the longer axis. These ridges when well marked have convex crests, thus giving to the garden an undulating appearance when viewed broadly; they are from 4 to 6 feet high and from 20 to 30 yards apart. In some parts of the area the ridges are very indistinct, and

it is impossible to state the exact number, though it is probably in the neighborhood of 25. The garden gradually rises toward the southwest; the difference in level between the lowest and highest ridge is about 125 feet, the former being 350 feet above sealevel. Practically all the boulders are the debris of the mountain in the immediate vicinity, not more than 1 per cent being Paleozoic and Laurentian erratics. The spaces between the boulders are quite empty, and in the northeast part, where the deposit is deepest, several excavations have been made, one of which was continued to the depth of about 20 feet without reaching bed rock or any accumulation of soil in the interspaces. It is probable, however, that the deepest parts do not much exceed 25 feet, as part of the country south is drained under the garden, in wet seasons the trickling of the water being distinctly heard, while on the occasion of one visit running water was noted in the 20-foot hole.

Separated by but a short distance from the above is the second deposit, which, commencing just below and north of the peak, fills in the triangular area between the porphyry and syenite. The ridges are at first irregular and are composed of very large and slightly rounded boulders, but gradually they broaden out and develop into a series as regular and better marked than those of the Devils garden. They run in a southwest direction—that is, at right angles to the trend of the ridges of the former deposit. The other characteristics are the same as in the case of the Devils garden, with the exception that this deposit is probably not so deep.

The character of the boulders in the Devils garden is such as to show that they came from the mountain immediately to the east, while those composing the second deposit were derived from the cliffs below the peak. With reference to the origin, it was thought both deposits were formed by the action of the waves during the post-Glacial submergence, and that, owing to a comparatively rapid rise of the land and the exposed position the mountain would then occupy, the finer detritus was washed out and deposited in the gravel and sand terraces which now flank the mountain in this vicinity. If that were the origin, then the Devils garden would have the character of a pocket beach and the second deposit that of a spit. The objection that has been made to the above is that no beaches now in process of formation show the above characteristics, there always being some packing of the finer detritus between the boulders. It has therefore been suggested that during the Glacial period, when the ice-sheet impinged against the projecting and prominent parts of the mountains, lines of drainage were developed owing to the obstructions encountered, and that the courses of these glacial streams were through the depressions, one to the east and the other to

the west of the peak. The torrents of water from the melting ice would partially or wholly round the fragments of rock, and the currents, being of sufficient force and volume, would carry away all the finer material and deposit it farther south. After the retreat of the ice-sheet, and during the subsequent submergence, these boulder plains would to some extent have been worked over by wave action, and thus arranged in successive parallel ridges or beaches as they are found at present. This dual origin seems to be the most probable, and more fully accounts for peculiarities of deposition which are characteristic of both deposits than if the whole work were ascribed to wave action alone.

Another point of interest, and worthy of mention, is a fissure spring which occurs on the northern ridge about half a mile east of the Devils garden. It is 500 feet above sealevel, and from its height and its being unaffected by seasonal variations it would appear that the water supply is derived from some higher land, in all probability the neighboring Laurentian country.

General Geology

The greater part of Rigaud mountain is composed of hornblende-syenite, which is pierced in the northwestern part by an intrusive mass of porphyry. The syenite is a uniform, massive, coarse grained rock, the exposed surfaces of which vary in color from pale red to grayish white. The rock joints into rough rectangular blocks, which are very numerous along the eastern margin. Red chert veins cutting the syenite are common in all parts of the area. They never exceed half an inch in width, and follow irregular courses, from a few inches up to a hundred feet in length. Along the northwestern margin a miarolitic structure is developed, evidently quite similar in character to that found in the Baveno granite on lake Maggiore. The cavities are of all sizes, from the most minute up to those having a diameter of 2 or 3 inches. They either contain well formed crystals of feldspar and quartz—the former occurring as Baveno twins—or crystals of quartz, to the total exclusion of the feldspar. This structure seems to indicate that, while the syenite is of deep seated origin, the then existing pressure was not so enormous as to prevent the formation of these cavities, which are more common in younger rocks of this class, such as the granite of the Castle Mountain mining district, Montana, described by Weed and Pirsson. The porphyry occupies a roughly triangular area, surrounded on two sides by the syenite. The most prominent part of the ridge (figure 1, plate 33), which faces the Ottawa river, forms the broad base. The rock shows considerable differentiation of magma. West of the Devils garden it is a quartz-syenite porphyry, which consists chiefly of feldspar phenocrysts in a felsitic groundmass.

zone being quite clear. The products are numerous shreds of kaolin, with an occasional minute grain of epidote or calcite. A mechanical separation by means of Thoulet's solution resulted in the oligoclase falling at a specific gravity of 2.62, the greater part of the microperthite at 2.56, and the remainder, which is probably almost pure orthoclase, at 2.52.

The microperthite has a poor form, occurring in large irregular or thick lath shaped interlocking individuals, with smaller grains between. The only approach to idiomorphism is when the individual is in contact with the quartz. In this case there is a partial development of some of the crystal faces. The cleavage parallel to *c* (010) is usually distinct; that parallel to *b* (001) less so.

The hornblende is the common green variety, with an extinction angle of 20 degrees. The pleochroism is strong, the absorption colors ranging from deep green to pale yellow tone. Though usually fresh, in a few instances it is seen altering to chlorite either along the cleavage planes or zonally from the interior (plate 33, figure 2). The greater part of the mineral follows the ordinary law, crystallizing out before the feldspar, and is generally intergrown with augite and biotite. It is rarely idiomorphic, occurring in prismatic sections with terminal faces, poorly developed, in rounded basal plates and irregular grains. The larger individuals frequently exhibit a poikilitic structure, inclosing differently oriented grains of feldspar. The borders of the individuals are seldom smooth, but send out little extensions, which, penetrating the feldspar, in many cases develop into a skeleton crystal and form a graphic intergrowth with the latter mineral. Figure 2, plate 33, shows this structure; the skeleton crystal is in a feldspar individual, but joined to and in optical continuity with the parent grain. At other times the skeleton is not so connected, and then usually presents a delicate lattice-like structure, made up of slender prismatic rods connected at intervals by narrow transverse sections. The most striking structure, however, is when the hornblende occurs in forms strongly allotriomorphic toward the feldspar. In this case it fills triangular and polygonal interstices between the feldspar individuals, and is often associated with quartz. Figure 1, plate 34, shows this excellently, though for purposes of better illustration biotite is reproduced instead of hornblende. Ramsay and Hackman* have described a similar structure in the nepheline syenite of Pontelitschorr, in which ægerine assumes the form superinduced by the nepheline and feldspar, and in the same rock a poikilitic intergrowth of arfedsonite and ægerine occurs with the colorless constituents.

Augite, when present, almost invariably occupies the center of pris-

* Das nephelinesyenitgebiet auf der Halbinsel Kola, Fennia 11, no. 2, p. 127.

FIGURE 1.—MICROPHOTOGRAPH OF RIGAUD HORNBLENDE-SYENITE

Dark mineral is biotite and the white is quartz. Strong allotriomorphism of biotite towards the feldspar is well shown. Crossed nicols × 38

FIGURE 2.—MICROPHOTOGRAPH OF RIGAUD QUARTZ PORPHYRY

Quartz phenocryst shows crenulated border due to secondary growth Crossed nicols × 47

RIGAUD HORNBLENDE-SYENITE AND QUARTZ PORPHYRY

matic sections of hornblende with the cleavage planes of both minerals coinciding. It is very pale yellow in color, and has an extinction angle of 40 degrees. It has altered considerably along the cleavage planes, and lines of basal parting, to a yellow or brown serpentinous material with granular structure, low double refraction, and aggregate polarization.

Biotite is subordinate in amount to the augite; it is brown and strongly pleochroic in deep brown and pale yellow tones with a greenish tinge. With a few exceptions it seems to have been one of the first materials to crystallize out, and occurs intergrown with the hornblende or as inclusions in the feldspar. When included in the latter, small idiomorphic forms are common both in prismatic and basal sections. In some instances the biotite shows that strong allotriomorphism toward the feldspar, which has been previously noted in the hornblende (see plate 34, figure 1). Though generally quite fresh, a few individuals have partially altered the chlorite along the cleavage planes, while others have been partially or wholly bleached to muscovite with a faint greenish tinge and higher double refraction.

Quartz is present in but small amount and fills angular spaces between the feldspar individuals. Fluid and opaque inclusions are very numerous in some grains.

The following accessory minerals exhibit but slight variations to their usual mode of occurrence: Apatite in very small amount is present in idiomorphic, prismatic, and basal sections, rounded grains and needles being rare. Colorless zircon occurs in square basal sections, stout prisms with pyramidal terminations, and in large and small grains, the latter being sometimes arranged in radiate clusters. Basal sections show the uniaxial and positive character of the mineral as well as the cleavage parallel to ∞P, which is distinct. When the zircon is included in the hornblende or biotite it is always surrounded by a pronounced pleochroic halo. The early crystallization of both the apatite and zircon is shown by their almost perfect form when included in the magnetite. Brown allanite is a rather common accessory in a few slides. It is found in graphic intergrowth with the feldspar, but usually occurs in rounded idiomorphic forms, included in the hornblende, and is always surrounded by a pleochoric halo. The individuals in $\infty P \overset{+}{\infty}$ sections are lengthened along the ortho-axis, and all are much traversed by cracks, the only distinct traces of cleavage noted being parallel to $o P$. Irregular zonal structure is invariable, and in all cases the interior is of a deeper color than the periphery. The pleochroism according to the zones is $\mathfrak{a}$ = deep brown, almost opaque; $\mathfrak{b}$ = brown, yellow; $\mathfrak{c}$ = light brown, pale yellow. Nearly all the magnetite which is in considerable amount is included in the biotite and hornblende. In the former it sometimes occurs

in small longitudinal plates arranged along the cleavage planes. A few grains of pyrite of cubic outline, with an alteration border of hematite, completes the list of constituents.

An analysis of the freshest rock procurable was made, the results of which are placed in the left-hand column, and, for the sake of comparison, one of the Plauen syenite* is given in the right.

	I.	II.
SiO_2	62.62	59.83
Al_2O_3	15.69	16.85
Fe_2O_3	2.07	—
FeO	4.73	7.01
MnO	.10	—
CaO	2.60	4.43
MgO	1.61	2.61
Na_2O	3.87	2.44
K_2O	5.95	6.57
H_2O	.61	1.29
	99.76	101.03
Specific gravity	2.68	2.73

I. Hornblende syenite, Rigaud (analyzed by O. E. Le Roy).
II. Hornblende syenite, Plauen bei Dresden * (analyst unknown).

The analysis of the Rigaud syenite bears out the result of the microscopic examination in that, as shown by the ratio of the alkalies, the orthoclase is the predominant feldspar in the microperthite. The rock is a normal syenite and compares favorably in composition with the typical rock of Plauen. The latter is higher in lime, iron, and magnesia than the former, and lower in silica, which is to be accounted for by its containing more of the ferro-magnesian constituent and less quartz. The total alkalies are almost the same for both rocks.

QUARTZ-SYENITE PORPHYRY

The porphyry, as has been previously mentioned, differentiates from a quartz syenite variety in the west of the mass to a quartz porphyry in the east, with an intermediate transitional band between.

Megascopically, the quartz-syenite porphyry consists of phenocrysts of feldspar, with a few of quartz, imbedded in a dark gray felsitic groundmass, which has an irregular conchoidal fracture. The feldspar, when fresh, is brownish gray in color, with good cleavage and high luster. It weathers to a pale red or grayish white. The phenocrysts have a poor form and vary considerably in size, from almost microscopic forms to

* Rosenbusch: Gesteinelehrbuch, chapter on Syenites.

those having a length of 1 centimeter. As a rule, they are very numerous and closely crowded together, but occasionally they occur very sparingly in bands and patches in the groundmass. Rounded grains of clear vitreous quartz are very subordinate in amount to the feldspar. The groundmass weathers to a light brownish gray, and the exposed rock often presents an angularly pitted appearance, due to the easy removal of the feldspar individuals.

Microscopically, the rock is composed of unstriated feldspar and quartz phenocrysts, with a few grains of plagioclase, biotite, hornblende, and zircon in a fine grained quartz-feldspar groundmass. Both the feldspar and the quartz occur in rounded idiomorphic and irregular forms, with crenulate borders and embayments filled with groundmass. The feldspar is apparently homogeneous, and presents a mottled appearance, due to kaolinization. It is evidently, from the analysis, a soda-orthoclase or anorthoclase. Twinning is rare and by the Carlsbad law only, with an irregular contact plane, which is usually filled with limonite. Strain shadows are common, and many individuals have been broken, especially where they are closely crowded together. A large number of phenocrysts were carefully freed from the base, and a mechanical separation made by means of Thoulet's solution. The freshest material fell at a specific gravity of 2.583, which would indicate, as the analysis has, a soda-potash feldspar. A few small rounded oblong individuals of clear plagioclase, which is probably albite, and some small grains of partially altered hornblende and biotite, are included in the feldspar.

The quartz occurs very sparingly in large phenocrysts, and frequently holds inclusions, both fluid and solid, the latter being opaque. Strain shadows, cracked, and broken individuals appear in every slide, and, as in the case of the feldspar, are no doubt due to the strain exerted during the final solidification of the magma.

The effects of resorption and secondary growth, which is the characteristic structure in both the feldspar and quartz, are better developed in the latter. In both minerals the growth is quite regular, taking the form of a crenulate rather than vermiculate border around the original grain and in optical continuity with it. The primary and secondary material is sometimes separated by a dark line or string of magnetite granules. This structure shows that, in addition to the usual resorption which goes on in rocks of this class, there was a further change in conditions which permitted the corroded grains to take on new material identical in composition with the original. Figure 2, plate 34, is a typical example of a quartz phenocryst illustrating this structure.

Through the kindness of Mr Pirsson, the writer was enabled to examine a section of quartz-porphyry from Wolf butte, Little Belt mountains,

Montana. In this rock the secondary growth of the quartz is much finer and better answers the definition of a coronal zone than does that of the Rigaud porphyry. In Weidman's description of the Utley metarhyolite* the secondary growth seems to be more identical, in form at least, with that of Rigaud. As this structure in the Rigaud porphyry presents no new features which have not been previously described by different writers, it is unnecessary to elaborate on the origin again.

The groundmass is composed principally of quartz and turbid feldspar, with a large number of idiomorphic grains of magnetite and a few of zircon, plagioclase, green hornblende, and brown biotite, the two latter being partially or wholly altered to chlorite, calcite, and limonite. The structure is microgranitic, and the allotriomorphic grains of feldspar and quartz are generally irregularly interlocked. Though very fine in grain, with a high power, the feldspar presents the same appearance as do the phenocrysts and is probably anorthoclase.

The quartz-syenite porphyry undergoes a variation in the southern part of the area, differing principally in the base, which megascopically is dull, compact, almost black in color, and weathers to a brownish gray. Microscopically, the feldspar and the quartz show the effects of resorption, but there has been no subsequent growth, the borders of the individuals being quite smooth. The groundmass is an extremely fine grained quartz-feldspar mosaic with a flow structure, accentuated by strings of magnetite granules, which coincide in direction with the flow. From this structure it is evident that this type may be regarded as transitional between the quartz-syenite porphyry and a quartz trachyte.

QUARTZ PORPHYRY

The quartz porphyry is separated from the above by a broad band of transition rock which shows a gradual increase in the number of quartz phenocrysts, and a corresponding decrease in the case of the feldspar. In hand specimens the quartz-porphyry is a light gray felsitic rock weathering to a pale red, and is thickly studded with rounded phenocrysts of clear vitreous quartz. Under the microscope the same constituents are present that were found in the quartz-syenite porphyry, with the exception that the quartz is in very large amount, while the feldspar is represented by only a few phenocrysts in each slide. At the contact of the quartz porphyry and the hornblende syenite the former loses its characteristic structure, and occurs as a granular mosaic of quartz and feldspar, the latter being present largely in the form of Carlsbad twins. This contact facies is a little coarser in grain than would be expected.

---

* Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin, 1898, p. 29.

Analyses of both varieties of the porphyry gave the following results:

	I.	II.	III.		
SiO_2	69.48	77.30	66.22		
TiO_2	—	—	.22		
Al_2O_3	14.19	11.08	16.22		
Fe_2O_3	3.89	3.91	1.98		
FeO	1.47	—	.16		
MnO	.12	—	Tr.	P_2O_5	0.10
CaO	.90	.68	1.32	BaO	.29
MgO	.68	.45	.77	SrO	.06
Na_2O	5.32	3.44	6.49	SO_3	.02
K_2O	4.34	3.22	5.76	Cl	.04
H_2O	.72	.28	.30	Fl and LiO_2	Tr.
	101.11	100.36			99.97
	Sp. gr., 2.63	Sp. gr., 2.64		O = Cl	.01
					99.96

I. Quartz-syenite porphyry, Rigaud (analyzed by O. E. Le Roy).
II. Quartz porphyry, Rigaud (analyzed by O. E. Le Roy).
III. Quartz-syenite porphyry, Bearpaw mountains, Montana (analyzed by H. N. Stokes).

The ratio of the alkalies in I shows that the soda molecule is the predominant one, and that the feldspar is undoubtedly anorthoclase. The ratio is comparable with that of the alkalies of III, in which rock the feldspar is also anorthoclase. In II the soda and potash are in almost equal amount, and as the feldspar is with few exceptions only present in the groundmass, the result indicates a close identity in composition between the feldspar of the base and the phenocrysts. The rather high percentage of iron is accounted for by the magnetite in the groundmass, while the small amount of the ferro-magnesian constituents is shown by the percentage of lime and magnesia.

APLITIC DIKE

The dike cutting the syenite is a rather coarse grained aplite, which when fresh is gray in color and weathers to a light reddish brown. Examined microscopically, it is seen to have a granular structure, and is made up of allotriomorphic grains of unstriated feldspar and quartz, with a few small individuals of plagioclase, apatite, and brown biotite. The feldspar is untwinned with the exception of a few Carlsbad individuals; it is very turbid and has numerous small flecks of brownish limonite along the cleavage and contact planes. Associated with it are a few striated individuals of oblong form, also much kaolinized. The former is probably orthoclase, the latter an acid plagioclase. The quartz

is subordinate in amount to the feldspar, and frequently holds inclusions of the latter mineral in a poikilitic manner.

LAURENTIAN HORNBLENDE-GRANITE GNEISS

The metamorphic rocks shown in the southeast corner of the map are, as before stated, a hornblende-granite gneiss and amphibolite.

The gneiss is a light colored rock of medium grain, with a rude foliation of the essential constituents. Microscopically, it is composed of allotriomorphic grains of feldspar, hornblende, and quartz, with accessory apatite, iron ore, and brown sphene. The iron ore is generally surrounded by the sphene and is probably ilmenite. The feldspar is cryptoperthite, consisting of an extremely fine parallel intergrowth of orthoclase and ultramicroscopic plagioclase; it has a specific gravity of about 2.59, and resembles the feldspar in the orthoclase gneiss of Trembling mountain, Quebec. The hornblende is the ordinary green variety, with an extinction angle of 16 degrees. The quartz is clear, with but few inclusions, and usually has an undulatory distinction.

AMPHIBOLITE

The amphibolite is very dark in color, rusty in appearance, and disintegrates easily into a coarse sand. The microscope shows the typical structure of a recrystallized rock, the feldspar and hornblende occurring in polygonal forms arranged about a central grain. The other constituents are biotite, garnet, apatite, and magnetite. The feldspar is turbid and is altering along the cleavage planes. It is twinned in broad lamellæ according to the albite law, and gives along the twinning plane an extinction angle of 33 degrees, which indicates labradorite. This was checked by a mechanical separation, which shows that it has a specific gravity of 2.69. The hornblende, which is in large amount, is brownish green, pleochroic, and has an extinction angle of 20 degrees. Reddish brown, strongly pleochroic biotite is in smaller amount than the hornblende, but crystallized before it. Prismatic sections are lengthened in the direction of the *a* axis and exhibit skeleton structure. The garnet is fresh, pale pink in color, and perfectly isotropic. It is much traversed by cracks and occurs in large, irregular individuals, either partly or wholly surrounding some of the hornblende and magnetite grains.

Relation of Rigaud to the other Igneous Hills in the Vicinity

The examination of Rigaud has shown that both in petrographic character and chemical composition the rocks are quite different from those composing the other hills on the same line. Two of these hills

have recently been worked up, and it has been found that the prevailing syenite, which is an alkali rich one, is associated with a more basic rock, such as theralite or essexite. Unless, therefore, the character of the magma changed considerably, Rigaud could hardly be regarded as being genetically connected to the rest of the series. On the other hand, considering the fact that Rigaud is associated with the older crystalline rocks, it seemed advisable to visit the nearest eruptive in the Laurentian to ascertain if it would have any relations in common with Rigaud. Accordingly a brief examination was made of an area of hornblende syenite which occurs on the border of the Laurentian in the townships of Grenville, Chatham, and Wentworth, about 13 miles northwest of Rigaud.

Grenville Area of Syenite and Porphyry

The Grenville syenite occupies an area of 36 square miles, and was described by Sir William Logan.* It cuts the Laurentian rocks on three sides, but to the south it is overlain unconformably by the Upper Cambrian. Like Rigaud, it is pierced in the western part by a small pear-shaped mass of porphyry.

Petrography

Hornblende Syenite

Megascopically, the syenite bears a close resemblance to that of Rigaud, but contains a larger proportion of quartz, which increases in amount until finally the rock passes into a granite. Microscopically, it is composed of feldspar and hornblende, with accessory augite, brown biotite, quartz, apatite, zircon, and iron ore. The feldspar varies in different parts of the area from an unstriated one to a microperthite, both being much kaolinized. The unstriated feldspar is homogeneous, and occurs in thick lath-shaped and irregular individuals, while the microperthite consists of a parallel intergrowth of the orthoclase and a finely twinned plagioclase. The latter has a better form than the orthoclase, and from its association is older. It occasionally occurs as Carlsbad twins, and is sometimes intergrown with hornblende in a graphic manner. The cleavage of both varieties is not very distinct.

The hornblende is in comparatively small amount, the larger grains being quite irregular, but many of the smaller, when they are included in the feldspar, are idiomorphic. The pleochroism varies from deep green to pale yellow, and the extinction angle is 19 degrees. The strong allotriomorphism toward the feldspar is not so common as in the Rigaud syenite. Some individuals are intergrown with a pale yellow augite, in

* Geology of Canada, 1863 Report, p. 40.

which case the latter forms the interior zone. Both minerals alter to a yellow serpentinous material.

The quartz occurs in rounded and angular grains, filling in interstices between the feldspar individuals. Fluid inclusions are numerous, and strain shadows invariable.

No analysis of the rock is available, but from the microscopical characteristics it seems to compare very closely with the Rigaud syenite.

QUARTZ-SYENITE PORPHYRY

The porphyry in hand specimens has a dark gray or reddish chert-like base, which holds a large number of phenocrysts of red feldspar. The rock joints with extreme ease into polygonal forms.

Under the microscope the following minerals were disclosed: Unstriated feldspar, quartz, and a few ragged plates of partially chloritized hornblende in an extremely fine grained groundmass, which, with the high power, resolved itself into a mosaic of quartz grains, and lath-shaped individuals of untwinned feldspar, the latter often being arranged in radiate clusters. The feldspar phenocrysts occur in rounded idiomorphic and irregular forms, and are apparently homogeneous, but very turbid. Twinning is not very common, but examples of both Baveno and Carlsbad twins are present in nearly every slide. The quartz phenocrysts are few in number, rounded in form, and hold numerous inclusions.

The usual resorption phenomena are pronounced both in the feldspar and the quartz, but only the latter shows secondary growth, the crenulated border being much finer than that found in the quartz of the Rigaud porphyry.

An analysis of the groundmass of the Grenville porphyry was published in the Geology of Canada, 1863 Report, and appears in the first column below.

	I.	II.
SiO_2	72.20	69.48
Al_2O_3	12.50	14.69
Fe_2O_3	—	3.89
FeO	3.70	1.47
MnO	—	.12
CaO	.90	.90
MgO	—	.68
Na_2O	5.30	5.32
K_2O	3.88	4.34
H_2O	.60	.72
	99.08	101.11
Specific gravity	2.62	2.63

I. Quartz-syenite porphyry, Grenville (analyst unknown).
II. Quartz-syenite porphyry, Rigaud (analyzed by O. E. Le Roy).

Though the comparison of the analyses is hardly a fair one, it nevertheless shows that the two rocks are closely identical in composition. A proper analysis of I would no doubt demonstrate that satisfactorily. From the ratio of the alkalies in I, the feldspar of the groundmass is evidently a soda-orthoclase.

Relation of the Rigaud and Grenville Areas

The brief description of the Grenville syenite and porphyry has shown that they are closely related petrographically to the similar rocks of Rigaud. The relations of the two areas are farther considered by means of the following cross-section, which is a northwest prolongation of the line *A B* on the Rigaud map.

Rigaud, it is seen, is thus separated from Grenville by a narrow band of Paleozoic rocks, which are supposed to overlie the Laurentian unconformably. It would seem, however, by no means improbable that the

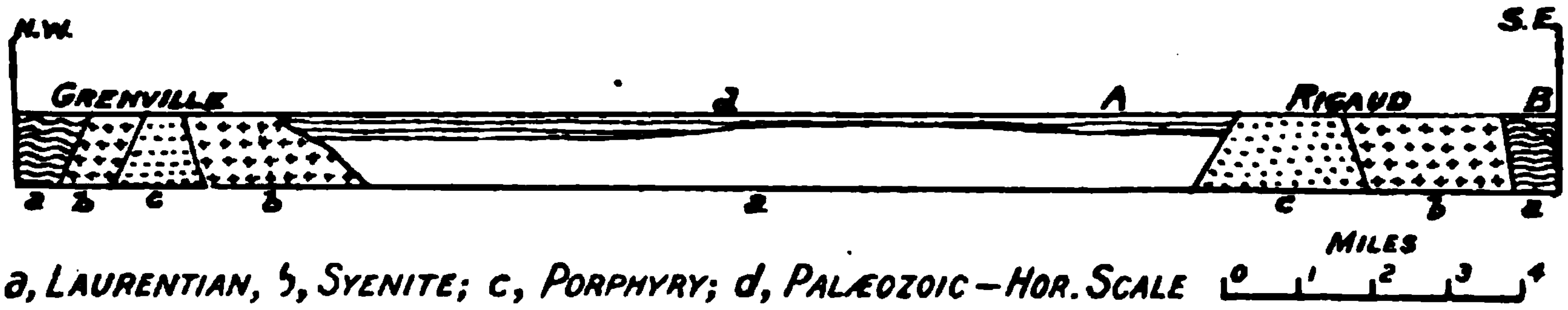


Figure 2.—*Section from Rigaud to Grenville.*

two areas might be continuous under the Paleozoic, and that the stratified rocks directly overlie the syenite instead of the Laurentian. Connected in such a manner, the eruptive mass would have a length of 20 miles, with a known maximum width of 9. This would give an area by no means enormous when compared with other masses of similar occurrence in the Laurentian, such as the granite intrusion northwest of lake Saint Peter, river Saint Lawrence, which is 30 miles long and 12 miles wide in the broadest part. A point which favors this connection is that Rigaud, from its field relations with Laurentian outliers, is practically on the border of that system, and it is only to the south and west of Rigaud that the Paleozoic plain is freely and uninterruptedly developed. If the above association be true, then Rigaud is of pre-Potsdam age, and, as in the case of Grenville, the eruption took place after the processes which caused the metamorphism of the Laurentian system had ceased and before the deposition of the Potsdam sandstone.

Summary and Conclusion

Rigaud mountain is the most western of a line of hills of igneous origin. It differs from the others in that, while they are of post-Silurian age, its age is doubtful, as the contact with the Paleozoic is concealed.

Rigaud is composed mainly of a normal hornblende syenite pierced in the northwest by an area of porphyry, which differentiates from a quartz syenite variety to a typical quartz porphyry.

The other hills, so far as known, consist of an alkali rich syenite. associated with a basic rock of the same petrographical province, such as theralite or essexite, both of which are totally different from the Rigaud rocks.

In the township of Grenville a mass of hornblende syenite of pre-Cambrian age cuts the Laurentian and is itself pierced by a quartz-syenite porphyry, both rocks being closely identical with those of Rigaud. From the proximity of the two masses it seems probable that either they are continuous under the Paleozoic or that they are genetically connected.

It concluding, it may therefore be stated that in all probability Rigaud has no genetic connection with the rest of the series, but a definite conclusion is abstained from until such a time when our knowledge concerning the other hills is so increased as to permit of the range being studied as a whole.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 395-444, PLS. 35-41 OCTOBER 31, 1901

SILURIAN AND DEVONIAN LIMESTONES OF TENNESSEE AND KENTUCKY

BY AUGUST F. FOERSTE

(Read before the Society December 28, 1900)

CONTENTS

Silurian Formations

The Cincinnati Anticline

A low anticlinal fold extends from north of the Ohio river, in a direction about south 25 degrees west, through the central parts of Kentucky and Tennessee. Its crest passes about 15 miles east of Cincinnati and 40 miles east of Nashville. It is known usually as "the Cincinnati anticline," although the name "Nashville dome" has been used at times for its southern half.

This fold was in existence in early Devonian, if not in Silurian, times. No Silurian formations occur along the crest of the fold in central and southern Kentucky, or in northern and central Tennessee. The width of the area within which Silurian strata are absent is 40 miles in central Kentucky; it is calculated to be about 55 miles in the region of the Cumberland river; and in central Tennessee, according to the observations of Professor Safford, it must be still greater—possibly 80 miles.

Surrounding this area, and overlapping the Ordovician on the flanks and ends of the anticline, are Silurian strata, the total thickness of which diminishes on approaching the crest of the fold.

The result is that Devonian strata rest on Silurian formations along the flanks and ends of the anticline, but along the crest, from north of central Kentucky to southern Tennessee, they rest directly on the Ordovician.

Relationships and Characteristics of Silurian Outcrops in Kentucky and Tennessee

In Kentucky, the most southern exposures of Silurian strata on the western flank of the anticline occur at the extreme southern end of

Nelson county, along Rolling fork. In Tennessee, the most northern exposures on the same side of the anticline occur about 7 miles west of Lafayette, in Macon county; north of Bledsoe, in the eastern part of Sumner county; and south of South Tunnel, in the same county. The distance between these points in Tennessee and the locality in Kentucky is 75 miles.

Within 75 miles the lithological features of formations may often change. Indeed, considerable variations are sometimes noticed within comparatively short distances. For instance, within 14 miles, on passing from the southern to the northern end of Bullitt county, in Kentucky, the Clinton changes from a white to a salmon-brown limestone. Within a distance of 15 miles, along the line separating Ripley and Jennings counties, in Indiana, the lower half of the main Osgood clay section is replaced by indurated clay, and the upper half by thin limestone layers. In the area under investigation, in Tennessee, the Osgood changes from a soft, thin bedded clay, at Bledsoe, to an indurated clay, at South Tunnel; the upper part is an impure limestone at Baker Station, and farther southwest almost the entire bed becomes an impure limestone.

There is, however, a remarkable similarity in the characteristics shown by the most southern Silurian exposures in Kentucky and the most northern outcrops in Tennessee. This similarity extends even to the minor subdivisions of the group.

SUBDIVISIONS OF THE SILURIAN

In comparing lithological features of different localities it is convenient to refer to the different subdivisions by distinguishing names. For this purpose various names were proposed in two recent reports of the geological survey of Indiana,* and the same names will be used in the present paper. Since the Tennessee area is geographically distinct from the Ohio, Indiana, and Kentucky area of outcrop, a second series of names is here proposed, referring to typical exposures in Tennessee, but the names taken from Tennessee localities will not appear in the following pages (see pages 407 and 421):

Indiana and Kentucky names.	*Tennessee names.*		
Louisville limestone.	Bledsoe limestone		Clifton limestone.
Waldron shaly clay.	Newsom shaly clay		
Laurel limestone.	Whites Bend limestone.	Centerville limestone.	
Osgood shaly clay.	South Tunnel bed		
Clinton limestone.	Baker limestone		

SILURIAN SECTIONS AT SOUTH TUNNEL AND BLEDSOE

The most accessible of the Silurian sections in northern Tennessee is that along the Louisville and Nashville railroad, near South Tunnel,

* Twenty-first and Twenty-second.

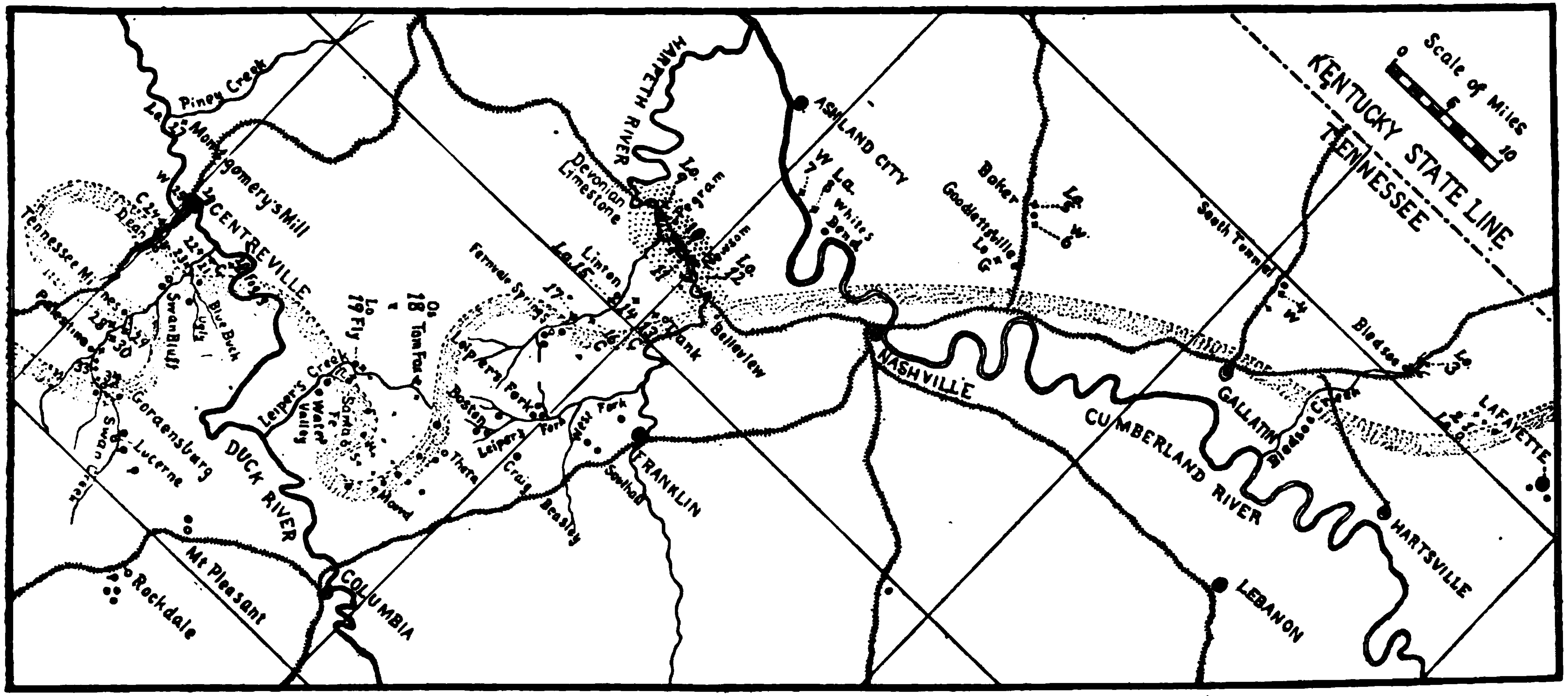


FIGURE 1.—*Silurian Outcrops on Western Flank of Cincinnati Anticline, Tennessee.*

The eastern limit of outcrop of the Silurian rocks is indicated by a dotted line, bordered on the east by a band of dots. The area of outcrop of the Devonian is indicated by a series of minute triangles. Exposures of Silurian rocks are indicated by a cross. Localities where Black shale rests directly on the Ordovician are indicated by dots. When the Waverly rests directly on the Ordovician, a short line is added to the dot. The Silurian formation which is in contact with the Black shale is indicated by placing over the number of the locality the initial letters of the formation: C, Clinton; Os, Osgood; La, Laurel; W, Waldron; and Lo, Louisville.

Black shale.

Waldron.

Top of Laurel.

FIGURE 1.—WALDRON AND LAUREL AT SOUTH TUNNEL

Laurel limestone.

FIGURE 2.—LAUREL LIMESTONE AT SOUTH TUNNEL

WALDRON SHALE AND LAUREL LIMESTONE

(figure 1, locality 4), about ten miles south of the Kentucky border. The railroad passes through two tunnels south of the station. The farther end of the second tunnel is five-eighths of a mile south of the station.

One hundred and fifty feet south of this tunnel the top of the Chattanooga Black shale is visible at the side of the railroad track. A railroad cut, one-seventh of a mile south of the tunnel, shows the lower part of this shale, and a second cut, one-third of a mile south of the same point, exposes its full thickness. At a third railroad cut, half a mile south of the tunnel, the Chattanooga shale (Devonian) rests on the Waldron shale (Silurian). From this point the Silurian section (figure 3) extends for a distance of about four-fifths of a mile along the railroad track. The strata are met in descending order.

The Waldron shale is only 5 feet thick at the cut mentioned (plate 35, figures 1 and 2). It weathers to a soft clay and contains very few fossils. Although it presents all the lithological appearances of the Waldron shale, as seen in Kentucky, its paleontological identity is better established by exposures farther southwest, preeminently by those at Newsom, 40 miles distant.

Beneath the Waldron shale lies the Laurel limestone (plate 35, figure 2), forming the main body of the cut. It is 28 feet thick. The stone is white and heavy bedded and, elsewhere in Tennessee, is frequently quarried as a building rock. At the top of the Laurel limestone, for a thickness of 2 to 3 inches, the rock is distinctly oolitic. The same oolitic phase is shown at the top of the Laurel limestone in many parts of Nelson and Bullitt counties, in Kentucky. Both in Kentucky and in Tennessee the top of the limestone, especially the oolitic layer, contains fossils which also occur, but in greater abundance, in the Waldron shale. At South Tunnel, *Whitfieldella nitida* occurs in the oolitic layer. *Orthoceras amycus* is found near the middle of the Laurel limestone. *Pisocrinus gemmiformis* is common near the base. This fossil is especially abundant at a fourth railroad cut, south of the semaphore electric signal, three-fourths of a mile from the tunnel (plate 36, figures 1 and 2). The base of the formation is here a crinoidal limestone. In Indiana and northern Kentucky, *Pisocrinus gemmiformis* occurs abundantly, both in the base of the Laurel limestone and in the limestone layers placed at the top of the Osgood beds. Farther south it becomes difficult to determine where to draw the line between the limestone layers belonging to the Laurel and those referred to the top of the Osgood beds. In Tennessee it is impossible to make such a separation, and here all of the limestone section is referred to the Laurel.

In the cut south of the semaphore signal, already mentioned, the

Laurel limestone rests on clayey material (plate 36, figures 1 and 2). Stratigraphically this undoubtedly represents the Osgood clay of Kentucky, but lithologically it is much less shaly. It occurs in thicker layers, some of which are slightly indurated, especially in the upper part of the section. The indurated layers are slightly lighter in color, thus producing a sort of banded appearance. The total thickness of the clayey material is 14 feet.

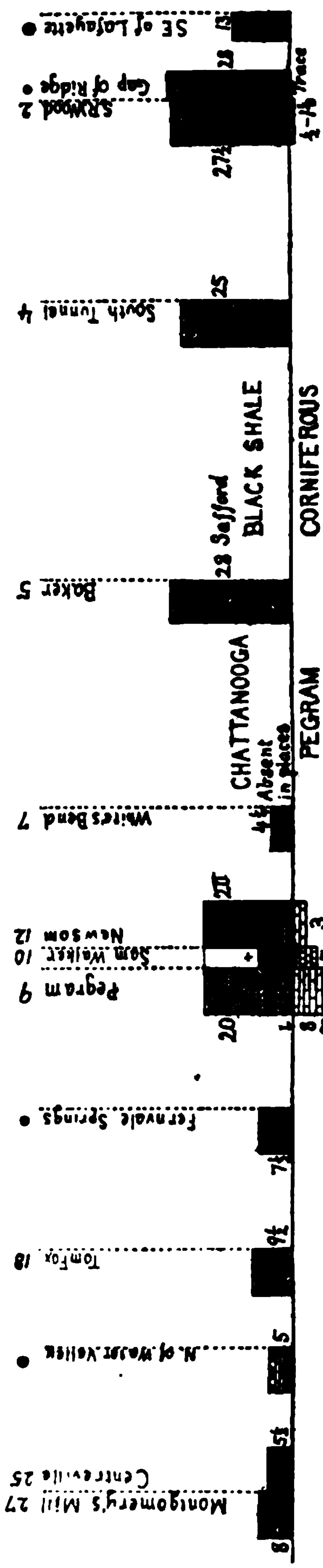


FIGURE 2.—*Sections of Tennessee Devonian Rocks.*

A much greater approach to the lithological characteristics shown by the Osgood clay sections in Nelson county, Kentucky, may be seen about a quarter of a mile north of Bledsoe (figure 1, locality 3), on the northeast side of the railroad trestle, north of Frank Earl's house. At this locality, which is about 14 miles east of South Tunnel, the Osgood clay is about 20 feet thick. It is a shaly clay, rather dark where not weathered, and the lower part is tinged with purple, resembling quite closely various exposures east of Bardstown, in Nelson county, Kentucky, and in the northern part of that county, along the Bullitt county line.

At South Tunnel the Clinton is first seen in the form of fragments of fossiliferous chert, east of the railroad and a short distance south of the fourth cut. The full section is seen a quarter of a mile farther on, at a fifth cut. The Clinton limestone is about 7 feet thick and the upper part contains a considerable quantity of fossiliferous chert. Loose fragments of this chert may be traced southward through the fields for several hundred yards from the last exposure. The lower part of the Clinton is a bluish limestone, containing much less chert and only a few fossils. It resembles so much the top of the immediately underlying Ordovician rock, in which fossils are also scarce, that it requires patience to determine where to draw the line between the Silurian and the Ordovician rocks.

Base of Laurel.

Osgood.

FIGURE 1.—LAUREL AND OSGOOD AT SOUTH TUNNEL

Laurel, base.

Osgood.

FIGURE 2.—LAUREL AND OSGOOD AT SOUTH TUNNEL

LAUREL LIMESTONE AND OSGOOD BED

Base of Clinton.

Top of Ordovician.

FIGURE 1.—CLINTON AND ORDOVICIAN AT SOUTH TUNNEL

Top of Louisville.

FIGURE 2.—TOP OF LOUISVILLE AT BLEDSOE

CLINTON, ORDOVICIAN, AND TOP OF LOUISVILLE

At South Tunnel the top of the Ordovician (plate 37, figure 1), which is a thick bedded limestone, presents a peculiar contorted appearance. Similar exposures of this rock occur at Whites Bend (plate 39, figure 1; figure 1, locality 8).

The section at South Tunnel includes only the lower half of the Waldron clay shale, and the Louisville limestone is entirely absent. The Louisville limestone is, however, well exposed at Bledsoe, 14 miles eastward. Along the railroad cut, above Sam Fleming's house, about a mile north of Bledsoe (plate 37, figure 2; figure 1, locality 3), the Chattanooga Black shale (Devonian) rests upon limestone. The 5 feet of limestone at the top of the section are white and crinoidal. The limestone below the level of the railroad track is fine grained and has been so much weathered that it is all more or less tinged with brown. Many of the courses are quite soft and weather away rapidly.

Nine feet below the Black shale and 1 foot above the railroad track *Conchidium knappi* was found. The same fossil is common 19 and 22½ feet below the Black shale. It is characteristic of the Louisville limestone horizon in Indiana and Kentucky. At the quarries east of Louisville, along Beargrass creek, it occurs above what is there called the "blue ledge." In the Bledsoe section *Pentamerus oblongus* is found on the hillside opposite C. F. Hedge's house, in the lower part of the Louisville limestone. Although cited in New York from the Clinton limestone, along the western side of the Cincinnati anticline it has so far been discovered only in the Louisville horizon. In fact, it is fairly common at this horizon, between Louisville and Charlestown, along the Ohio river, and at Clermont, in southern Bullitt county, Kentucky. The fossils occurring in the Louisville horizon at Bledsoe are enumerated later.

LITHOLOGICAL CHARACTER AND THICKNESS OF TENNESSEE SILURIAN FORMATIONS

Explanation of the section.—While the various subdivisions of Silurian age recognized in Indiana and Kentucky can be readily identified in northern Tennessee, several of them change so much on being followed southwestward that they can be traced through central and southern Tennessee only with difficulty. This is especially true of the Clinton limestone and the Osgood clay shale.

The following notes will make the accompanying drawings more intelligible. In the first set of sections of Silurian strata accompanying this paper (figure 3) the sections have been so arranged as to place the top of the Osgood bed at the same level, the intention being to indicate the variation in thickness of the various formations on following them

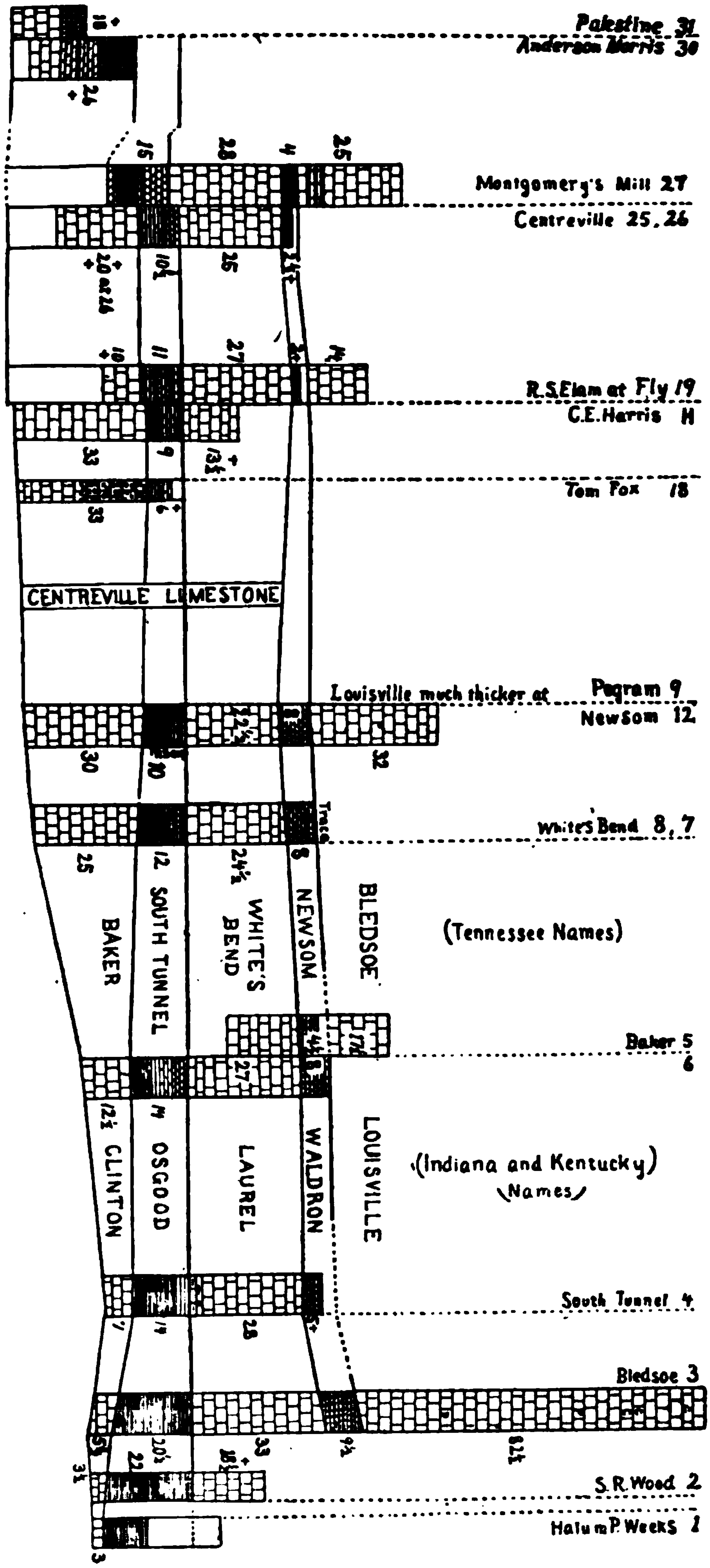


FIGURE 3.—*Sections showing Variations in Thickness of Tennessee Silurian Rocks.*

FIGURE 1.—CLINTON AT BAKER

FIGURE 2.—CLINTON AT WHITES BEND

CLINTON AT BAKER AND WHITES BEND

southwestward along the western flank of the anticline. No evidence of unconformity between any of the Silurian strata has been found. The appearance of unconformity shown by some of the sections is due to the method of drawing the sections. The measurements along the vertical lines bearing the names of the localities are accurate. The drawings are intended to indicate variations in thickness of formations on being traced through the state, and apparent variations in thickness at the individual localities are again due to the method used in drawing.

Variations in Clinton limestone.—An examination of these sections shows that the Clinton thins eastward on passing up the flank of the anticline. It also changes in lithological appearance. Near the houses of Halum P. Weeks (figure 1, locality 1) and S. R. Wood (locality 2) the Clinton is a bluish limestone, which varies from 3 to 3½ feet in thickness and contains *Favosites favosus* and *Dalmanella elegantula*. At Bledsoe (locality 3), beneath the trestle already mentioned, it is about 5¾ feet thick, has a whitish color, and contains the same fossils.

At South Tunnel (locality 4) its thickness has increased to 7 feet. The upper part contains much more chert than at the preceding localities. The chert occurs chiefly in the form of thin layers, including a considerable variety of fossils. Similar chert and fossils occur in the upper part of the Clinton at Baker (locality 6), 19 miles southwest of South Tunnel, especially in the field south of the quarries. Although the discovery of any considerable fauna in this chert requires patient search, a few species are sufficiently common to be readily found. The localities at South Tunnel, Baker, and Goodlettsville are the most favorable for the collection of Clinton fossils so far known in Tennessee, on the western flank of the anticline. At the southern end of the quarry, at Baker (plate 38, figure 1), the Clinton is 12 feet thick. It is a rather thin-bedded whitish limestone, containing irregular layers and nodules of chert.

At the entrance from the pike to the stone quarries, one mile west of Goodlettsville (locality *G*) the Clinton rests upon a layer of Ordovician limestone full of fragments of *Isotelus*. The Clinton chert is fairly abundant along the hillsides, and enough fossils are found to readily establish the horizon.

At Whites Bend (plate 38, figure 2; figure 1, locality 8) the Clinton has increased to 25 feet. The interbedding of the limestone with chert is very marked, especially near the top of the section. Good exposures occur along the pike, west of John Scott's house. The best fossils were found in the gullies west of John Suell's home.

At Newsom (locality 12) the contact between the base of the Osgood bed and the top of the Clinton limestone is best exposed along the rail-

road a quarter of a mile west of the station, at a recently opened quarry. The lowest exposure of Clinton rock occurs along the railroad track near the station. A covered space of 18 feet intervenes between the lowest exposure of the Clinton and the top of the Ordovician rocks in the banks along the river. The thickness of Clinton rock actually exposed is 30 feet, but the covered interval makes it possible that the total thickness may be greater. A comparison with other sections, farther southward, makes it more probable, however, that the unknown interval is chiefly occupied by soft Ordovician rocks. It is interesting to note that Mr Charles Schuchert cites *Triplecia ortoni* as occurring in the Clinton at Newsom. This is one of the most widely distributed and most characteristic fossils of the Clinton in Ohio and along the western flank of the Cincinnati anticline, although not often represented by many specimens.

All of the Silurian limestone, 33 feet thick, underlying the Black shale (Devonian) above Carol Litton's house, a quarter of a mile above the Tom Fox locality (locality 18), in the northern part of Maury county, belongs to the Clinton. Farther down Leipers creek, at the old Oil well, the top of the section must belong in part to the Osgood horizon.

At Centerville, along the railroad track (locality 25), at least 12½ feet of limestone, underlying beds which weather more readily, must be assigned to the Clinton. They contain *Triplecia ortoni* and other fossils. An interval of 20 feet between the lowest Clinton exposure along the railroad and the Ordovician limestones which line the river bank does not present exposures. Since at least 20 feet of Clinton limestone are exposed at the bridge northeast of town, it is certain that at least a part of the covered interval northwest of town is occupied by Clinton rocks. Whether the total thickness reaches 30 feet is uncertain.

Along Swan creek, west of Anderson Morris' house (locality 30), at least 26 feet of Clinton are exposed, and the base is not seen.

So far as may be determined at present, the Clinton diminishes in thickness rapidly in passing from Whites Bend northeastward to the Wood and Weeks localities, but between Whites Bend and the most southern exposures along the flank of the anticline, showing the entire thickness of the Clinton between the Ordovician and the Osgood beds, the thickness remains either comparatively constant or is slightly diminished.

The cherty character of the Clinton, as seen near Newsom and Linton, is not so strongly in evidence farther southward. Near Carol Litton's house only the upper half of the Clinton is very cherty. Near Centerville only the uppermost layers are cherty. This is true also of the exposures along the valley of Swan creek. Near the home of Anderson Morris (locality 30) the middle and lower part of the Clinton consists of whitish limestone, free from chert.

Variations in Osgood bed.—The Osgood bed, at its most northeastern exposures, is a clay shale. It here also presents its greatest thickness: 22 feet at the S. R. Wood locality (locality 2) and 20 feet at Bledsoe (locality 3).

Southwestward it changes its lithological character rapidly. At South Tunnel (locality 4) the clay is more indurated and calcareous, especially near the top of the bed. The more shaly and the more indurated layers are interbedded, producing a banded appearance. The total thickness of the Osgood bed at this point is 14 feet.

At Baker (locality 6) the upper part of the Osgood bed is sufficiently indurated to be quarried, although the rock disintegrates so readily that its use is to be discouraged. The upper half of the indurated beds becomes a crinoidal limestone at the south end of the quarry. The indurated rock is 7½ feet thick. It is underlaid by 6½ feet of soft clay shale, best exposed above the Clinton ledge at the southern end of the quarry. The total thickness of the Osgood bed at this locality is therefore 14 feet. The presence of the crinoidal material in the upper part of the section makes it difficult to distinguish the top of the Osgood bed from the base of the Laurel limestone.

This difficulty increases on going southwestward. At Whites Bend (locality 8) the larger part of the Osgood bed is soft and weathers readily, but near the top the clay becomes more indurated and calcareous, and gradually merges into the overlying Laurel limestone. It is impossible to determine the precise line of separation between the two formations.

The best exposure of the Osgood bed near Newsom (locality 12) is along the road following the north side of the Harpeth river westward toward Foster and Creighton switch. The clay section is here 11 feet thick. The lower 2 feet are purplish colored, and the immediately overlying beds are more or less tinged with the same color. The shaly character of the Osgood formation has largely disappeared. It has more the appearance of a soft clay rock, the layers of which are not sufficiently thin to give it a distinctly shaly character. At the top the bed is more indurated, and is not readily distinguished from the Laurel limestone. This is true also at the quarry along the railroad, an eighth of a mile west of Newsom. Here the quarry rock (Laurel) is underlaid by 1 foot of soft limestone, readily weathering; then 1 foot of limestone, and 6½ feet of indurated clay, harder near the top, undoubtedly belonging to the Osgood bed. These exposures form a transition to those south of the Harpeth River valley, where the Osgood bed is represented by soft limestones, readily disintegrating.

South of the home of Johnson V. Linton (locality 15) 21 feet of Laurel

limestone are underlaid by 6 inches of soft limestone, 4 feet of harder limestone, 1½ feet of limestone weathering more readily, and 5 feet of clayey limestone. also weathering readily. The base of the Osgood bed is not exposed. These softer limestones occupy the same horizon as the shaly Osgood clays at South Tunnel and Bledsoe.

At the base of the cliff west of R. S. Elam's house, a mile above Fly's store (locality 19), the Osgood bed consists of soft limestones, weathering more readily than the Laurel limestone above. In fact, the Osgood bed weathers so readily that it is difficult to find good exposures in the Leipers Creek valley. At the Elam locality the Osgood limestone contains a number of large specimens of *Orthoceras*. The presence of large specimens of *Orthoceras* becomes rather characteristic of the Osgood limestone along the valley of the Tennessee river, farther westward. Opposite the home of C. E. Harris, on Snow creek (locality *H*), 2 miles east of Santa Fé, only the harder layers of Osgood limestone are preserved. Their identity is established by their position between the cherty layers forming the upper half of the Clinton and the fairly well exposed base of the Laurel limestone. Above Carol Litton's house the Osgood bed is absent. At the Oil well below Tom Fox's home (locality 18) the 6 feet of limestone beneath the Black shale and overlying the cherty Clinton belong to the Osgood horizon.

At Centerville, along the railroad (locality 25), the Laurel limestone, 25 feet thick, is underlaid by a somewhat softer limestone 4 feet thick, weathering in some places to a clayey calcareous rock. Beneath this is a calcareous rock 6½ feet thick. In some places it is a rather firm limestone, but it also occurs in the form of soft and shaly strata, readily weathering, although strongly calcareous. As a matter of fact, the Osgood bed is here lithologically simply a softer phase in the general Silurian section, although paleontologically it separates the fauna of the Clinton limestone below from that of the Laurel limestone above.

At Montgomery's mill (locality 27), on Piny creek, the Osgood bed forms likewise merely the softer phase at the base of the general limestone section.

It will be noticed from the preceding statements that the Osgood bed, on being followed from its most northern outcrops in Tennessee southwestward along the flank of the anticline, changes from a soft shaly clay, easily distinguished from the limestones above and below, first to an indurated clay, especially near the top of the section, next to an even harder calcareous rock, again chiefly at the top of the formation, and, finally, at Linton and along the various tributaries of Duck river, it becomes a soft limestone. Where the Osgood bed is represented by limestone, its identity can be established only with difficulty. While, there-

FIGURE 1.—CLINTON AND ORDOVICIAN AT WHITES BEND

FIGURE 2.—WALDRON AT NEWSOM

CLINTON, ORDOVICIAN, AND WALDRON

A

FIGURE 1.—LEVEL OF PEGRAM LIMESTONE
At "A," on hillside southeast of Newsom

FIGURE 2.—PEGRAM LIMESTONE AT NEWSOM

PEGRAM LIMESTONE

fore, in northern Tennessee and in Kentucky and southern Indiana the Osgood bed forms a well marked horizon, south of the Cumberland river, especially south of the Harpeth river, it can be recognized only when followed from outcrop to outcrop, or studied in connection with the fossils found in the Laurel limestone above and the Clinton limestone below. South of Harpeth river, where the Clinton-Osgood-Laurel beds form practically a single lithological unit, the name Centerville limestone may prove convenient as a general name for this series (figure 3).

Constancy of Laurel limestone.—As compared with the Clinton limestone and Osgood bed, the Laurel limestone is constant in character, both in thickness and in lithological appearance. It is a whitish limestone, at some localities slightly blotched with red. Almost all the Silurian quarries at present operated in Indiana, except those at Utica and Charlestown Landing (Louisville limestone), along the Ohio river, belong to this horizon. The numerous quarries east of Clermont, in Bullitt county, Kentucky, are in the Laurel limestone. The quarries along Beargrass creek, east of Louisville, are the only important Silurian quarries known in western Kentucky which belong to another horizon, the Louisville limestone. In Tennessee the Laurel limestone could be quarried at South Tunnel (locality 4). It was formerly extensively quarried at Baker (locality 6) and west of Whites Bend (locality 7). It is at present actively operated at various points west of Newsom (localities 11, 12), and local quarries are opened at Linton (locality 15) and at Centerville (locality 26).

Constancy of Waldron shale.—The Waldron clay shale is another remarkably constant bed. North of Decatur county, in Indiana, it changes into a limestone horizon. From Waldron, in Indiana, southward to Newsom (plate 39, figure 2; figure 1, locality 12), in Tennessee, it consists of shaly clay, sometimes interbedded with a little thin limestone. It is very fossiliferous at numerous points in Indiana; at most localities in Kentucky it is nearly barren or contains only a small fauna, and this is also true of most localities in Tennessee; but at Whites Bend it is fairly supplied with fossils, and at Newsom it contains a rich fauna, rivalling the best localities in Indiana. Its thickness usually varies in the neighborhood of 8 feet, but along Duck river its thickness does not appear to exceed 4 feet. It has so far not been identified farther south or west in Tennessee than Montgomery's mill (locality 27).

Constancy of Louisville limestone.—East of Louisville, along Beargrass creek, the Louisville formation is a whitish limestone. All of the limestone is quarried, although some of the layers are rather soft and seem to weather readily. Where long exposed the softer rock has disintegrated so that the section seems to consist of fairly hard limestone layers separated by more or less covered intervals.

At Bledsoe (locality 3) only the harder layers of limestone are well exposed, the softer layers have disintegrated and have allowed the better preserved layers to drop. It is evident that at one time the section must have consisted of fine-grained, white limestone; harder, more calcareous layers being interbedded with softer, more argillaceous beds. At Newsom (locality 12) the exposures are poor, due, no doubt, to the presence of readily weathered beds. At the bridge west of Pegram (locality 9) the upper 10 feet of the section are occupied by calcareous clay (plate 41, figure 1) containing numerous fossils. The limestone beneath, above the level of the railroad track, is lithologically very similar to the poorer quality of limestone at Louisville. Underlying this rather soft limestone, below the level of the railroad, are soft, clayey beds, and, still lower, in the bed of the wet weather stream toward the north, there is a series of hard limestone layers, containing *Spirifer foggi* and other characteristic Louisville limestone fossils.

The Louisville limestone is known at present only where unconformably overlaid by the Black shale. Since it is probable that erosion took place previous to the deposition of the Black shale, it is not possible to form even an idea of the original thickness of this formation. The thickest section measured in Tennessee is that at Bledsoe, 82½ feet.

THE SILURIAN-DEVONIAN UNCONFORMITY

The Silurian formations in Tennessee are overlaid unconformably by the Devonian. The evidence for this is abundant (figures 3, 4, and 5). The determination of the precise character of this unconformity was made possible by the recognition of the various subdivisions of the Silurian, as defined above.

At South Tunnel (figure 1, locality 4) the Chattanooga Black shale (Devonian) rests on only 5 feet of Waldron clay shale. The upper part of the latter bed was probably removed before the deposition of the Black shale. At Bledsoe (locality 3) the Black shale rests on at least 82 feet of Louisville limestone. At the home of S. R. Wood (locality 2) the Black shale rests on 18½ feet of Laurel limestone. At the exposure near Halum P. Weeks' house (locality 1) the base of the Black shale is separated by an interval of 18 feet from the highest exposed part of the Osgood shale. The thickness of Osgood clay shale exposed is 11 feet. At the Weeks locality, therefore, the Black shale rests on a layer 22 feet lower in the scale than the layer on which it rests at the home of S. R. Wood. Along the road leading southward down the hill from the Gap of the Ridge the Black shale rests directly on the Ordovician. The structure may be that of a syncline, with its trough near Bledsoe. At Bledsoe the Black shale rests on the highest Silurian strata exposed

Pegram limestone.

Fossil shale.

Louisville limestone.

FIGURE 1.—LOUISVILLE AND PEGRAM BEDS WEST OF PEGRAM, NEAR THE BRIDGE

Black shale.

Pegram limestone.

FIGURE 2.—PEGRAM LIMESTONE WEST OF PEGRAM, NEAR THE BRIDGE

LOUISVILLE AND PEGRAM BEDS

along the flank of the anticline. East and west of Bledsoe it rests on lower formations, the amount of unconformity being greatest eastward, as already shown.

At Baker the unconformity may easily be recognized. North of the station (locality 5) the Black shale rests on 17½ feet of Louisville limestone. At the quarries southeast of the station (locality 6) the Black shale rests on the Waldron shale. Near the northwestern end of the quarry it rests on the full thickness of the shale, 8 feet, but near the eastern end of the quarry only on the lower half.

At Goodlettsville the Black shale rests on about the same thickness of Louisville limestone as north of Baker Station.

Along the road to Ashland City, west of Whites Bend, the Black shale rests usually on variable thicknesses of Waldron shale, and where this is absent on the Laurel limestone. At the old quarries, 600 feet west of John Suell's house (locality 7), the Black shale is absent and the Waverly rests on the top of the Laurel limestone. At the large quarry, along the road farther eastward, the Black shale, having a

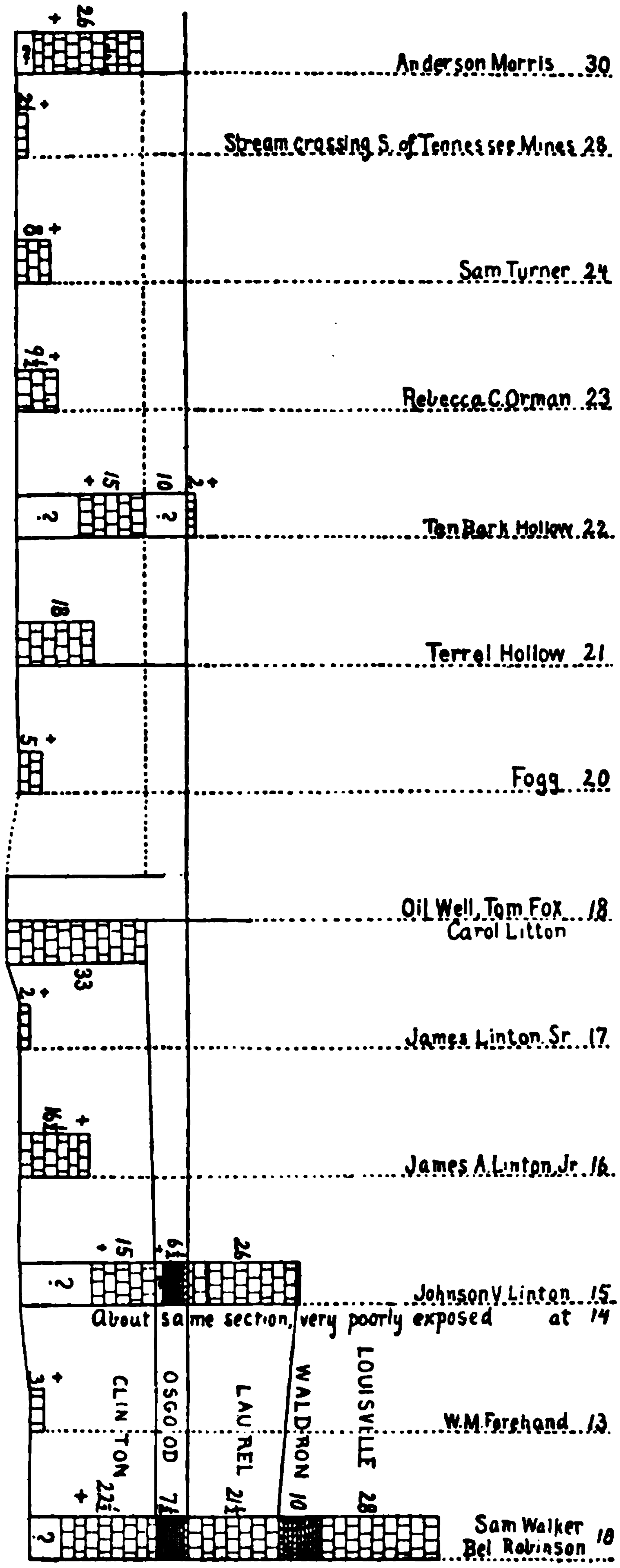


FIGURE 4.—Additional Sections of Tennessee Silurian Rocks.

thickness of 4 feet, rests on the Waldron shale, which here varies from 2½ to 8 feet in thickness in different parts of the quarry, thus giving evidence of considerable unconformity within a comparatively short distance. Several hundred yards from the road, at a quarry northeast of that last mentioned and up a little valley, the Black shale is absent and the Waverly rests on the Waldron shale, 8 feet thick. At one point a few blocks of Louisville limestone intervene between the top of the Waldron shale and the Waverly. A considerable distance farther eastward, a quarter of a mile west of John Scott's house (locality 8), west of Whites Bend, the Black shale rests either on 2 or 3 inches of Waldron shale or on the top of the Laurel limestone. Next to the Newsom localities the exposures near John Suell's house furnish the greatest variety of Waldron fossils, but not in as great abundance.

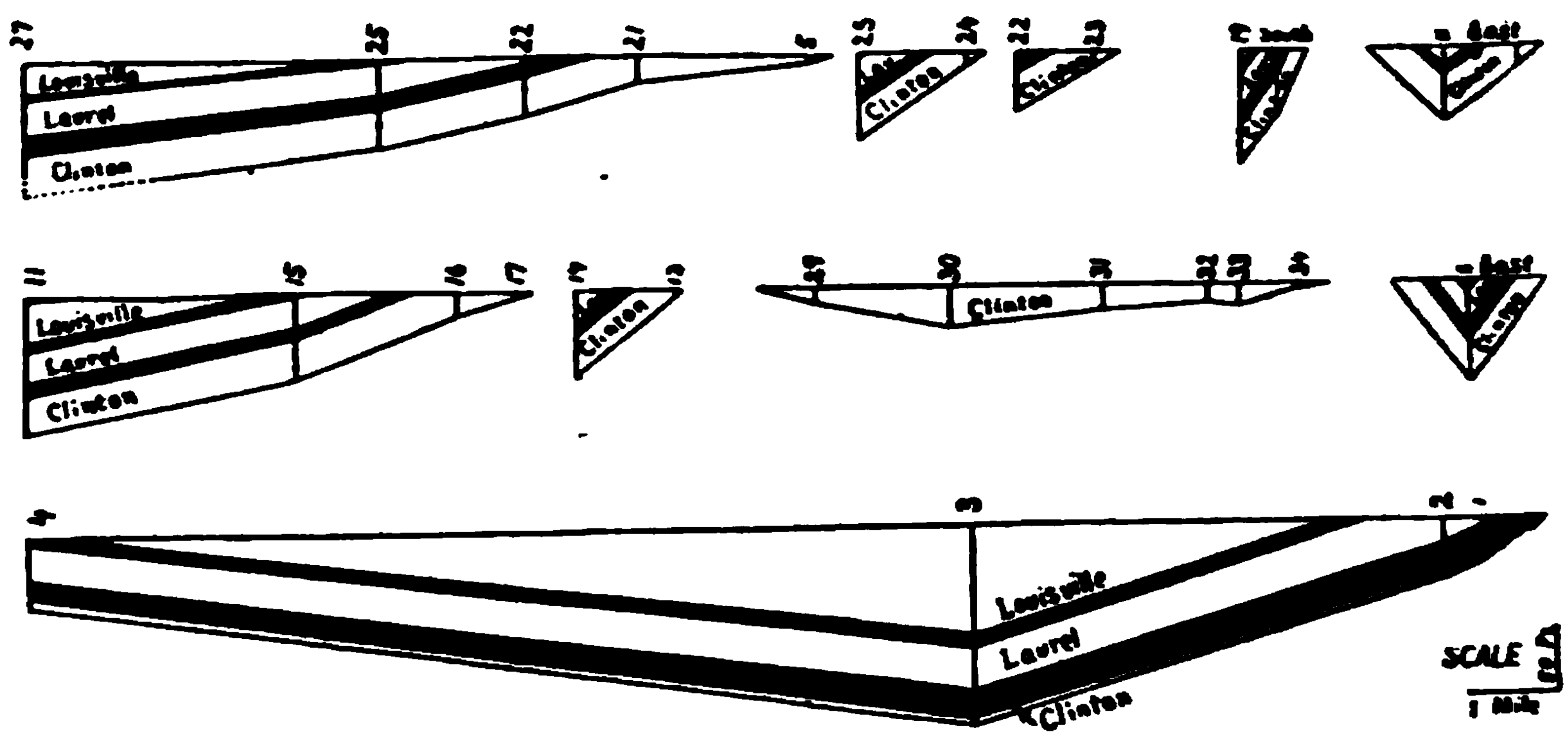


Figure 5.—*Rapid Thinning incident to Unconformity.*

The diagrams show the very rapid thinning of Silurian formations where unconformably overlaid by the Devonian.

Along the Harpeth river, between Newsom and the bridge at Pegram, the Black shale is underlaid by Devonian limestone, varying from 3 to 12 feet in thickness, corresponding apparently to the Devonian limestones of Kentucky and southern Indiana. The top of the limestone contains fossils belonging to the horizon of the Sellersburg limestone of southern Indiana and Kentucky and the Hamilton of New York. The middle and lower part of the limestone contains *Nucleocrinus verneuli*, a characteristic corniferous fossil. It is here called the Pegram limestone.

At Newsom, southwest of the station, beyond the quarry nearest the railroad (locality 12), the Pegram limestone (plate 40, figures 1 and 2) rests on Louisville limestone having a thickness of 32 feet, poorly ex-

posed. Southeast of Sam Walker's house (locality 10), along the river and about three-fourths of a mile west of Foster and Creighton's switch (locality 11), the Pegram limestone rests on Louisville limestone having a thickness of 28 to 30 feet. At the bridge, a mile and a half west of Pegram, the Pegram limestone rests on an unknown thickness of Louisville limestone. Including the softer, more shaly courses at the top of the section, at least 30 feet of Louisville rock are exposed south of the railroad; adding the strata exposed in the ravine extending north from the railroad, the total thickness may exceed 50 feet. The Waldron shale belongs stratigraphically at a still lower horizon, but it is not exposed here.

While at Newsom (locality 12) 32 feet of Louisville limestone intervene between the Pegram limestone and the Waldron shale, at the quarry south of J. V. Linton's house (locality 15) the Black shale rests directly on the top of the Laurel limestone, the Louisville limestone and Waldron shale being absent. About 2 miles southward, where the road to Fernvale crosses the creek, half a mile beyond the house of James A. Linton, Jr. (locality 16), the Laurel limestone and the Osgood bed are also absent, so that the Black shale rests on 16 feet of cherty Clinton limestone. Just north of a little branch a quarter of a mile south of the home of James Linton, Sr. (locality 17), most of the Clinton even is absent, the thickness of the Clinton (cherty limestone) beneath the Black shale being only 2 feet. A mile farther south, at the school-house, the Black shale rests on Ordovician rocks.

The Johnson V. Linton locality is about half a mile south of the Linton post-office or the Elliston store. As stated in the last paragraph, the Black shale here rests on the top of the Laurel limestone. About a mile eastward, on the road to Tank, an eighth of a mile before reaching a negro church, the hillside north of the road is covered with fragments of chert containing a fair number of Clinton fossils. The highest chert fragments are found 23 feet above the road, and since the Black shale is seen only 38 feet higher up, resting on limestone containing *Pisocrinus gemmiformis*, it is probable that the Black shale here also rests on the top of the Laurel limestone. However, at the foot of the hill, half a mile west of Tank, above the spring south of the home of W. M. Forehand (locality 13), only 3 feet of cherty Clinton limestone are seen beneath the Black shale. For 10 feet below the Clinton exposure the rock is covered. This part of the section is probably occupied by the soft clayey layers, which are quite characteristic of the top of the Ordovician in the area west of Franklin.

At the Oil well, a short distance south of Tom Fox's house (locality 18), along a branch of Leipers creek the Black shale rests on 6 feet of

Osgood limestone. About a quarter of a mile farther north, a short distance above the home of Carol Litton, it rests on the top of the Clinton. It rests on the Clinton also a mile east of the mouth of the Oil well branch, up Leipers creek.

A mile above Fly's store, on Leipers creek, the Black shale rests on Louisville limestone 14 feet thick. The age of the Louisville limestone is shown by the presence of Waldron shale at one point near the top of the bluff. About five-eighths of a mile straight southward, on the road from Fly to Santa Fé, the Black shale rests on the lower half of the Laurel limestone. Only the cherty beds forming the upper half of the Clinton are well exposed. In this cherty part of the Clinton, especially near the top of the section, *Halysites catenulatus* is often very common—a fact characteristic of the Clinton in Maury county, and observed also at Newsom and at the spring-house belonging to Belfield Robinson, south of the Sam Walker farm (locality 10).

East of the home of C. E. Harris (locality *H*) the Black shale rests on Laurel limestone 13½ feet thick. About a mile and a quarter directly southward, northeast of the home of Mat Sowal (locality *S*), a large part of the section is not exposed. The base of the Clinton is, however, well shown, and chert fragments with Clinton fossils occur up to a level of 33 feet above the base. Above this, for a distance of 25 feet, there are no exposures; then 21 feet of limestone are seen. From this it is probable that the Black shale rests on Louisville limestone.

Two miles directly north of C. E. Harris' house, on the road from Snow creek to Bethel church, the Black shale rests on Clinton limestone 15 feet thick. A mile and a quarter northward, along the same road, below the house of Peter Thompson, the Black shale rests on the Clinton, apparently on the top of the full section.

A mile and a half northeast of C. E. Harris' house, opposite the home of J. W. Skelley, above the spring, the Black shale rests on 15½ feet of Clinton limestone. About the same distance southeast of the C. E. Harris locality, on the road to Mowd, the Clinton beneath the Black shale has a thickness of 13½ feet.

At Montgomerys mill (locality 27) the Black shale rests on Louisville limestone 25 feet thick. On the road leading from Centerville station into town it rests on Waldron clay shale 2½ feet thick. Along the railroad southwest of town the Waldron beneath the Black shale measures only 4 inches. Above the spring in the Tan Yard hollow (locality 22), 2¾ miles southeast of Centerville, 15 feet of solid white cherty Clinton are exposed. The total Clinton section is not seen. Above this ledge is a space of about 10 feet in which very little rock is exposed. This is probably occupied by the soft shaly Osgood layers. Overlying this space

is white limestone 2 feet thick, which probably belongs to the base of the Laurel. The Black shale lies immediately above. About 1¾ miles farther eastward, at a spring in Terrel hollow (locality 21), the Black shale rests on Clinton limestone 18 feet thick. At Foggs post-office (locality 20), 1½ miles southwest of Tottys Bend post-office, 3½ miles northeast of the last locality, the Black shale rests on very hard white Clinton limestone 5 feet thick and contains chert nodules.

While at Centerville (locality 25) the Black shale rests on the Waldron shale, two miles south of Centerville, in the hollow near Sàm Turner's log house (locality 24), a short distance north of Mrs Isabella Wiss' home, Black shale rests on only 8 feet of Clinton limestone containing layers of cherty nodules. A short distance southeastward, at the Dean phosphate quarry, the Black shale rests on the Ordovician limestone.

Moreover, while above the spring in the Tan Yard hollow (locality 22) the Black shale rests on rock believed to belong to the base of the Laurel limestone, a mile and a half farther southward, about 225 feet north of the spring north of the home of Mrs Rebecca C. Orman (locality 23), the Clinton beneath the Black shale has a thickness of only 9½ feet. It contains chert nodules. At Swan bluff, farther south, the Black shale rests on the Ordovician.

At the Tennessee Mines, 4½ miles south of Swan bluff, the Black shale rests on the Ordovician. A short distance farther south, where the road going downhill crosses a little stream (locality 28), the Black shale rests on several chert layers, which have a thickness of 2½ feet. Only the chert is preserved, the intermediate limestone having decayed and disappeared. Beneath is cross-bedded Ordovician limestone. On the other side of Swan creek, on the road leading from Tennessee Mines across the creek and then down the east side of the valley, is a bluff (locality 29) of massive white limestone about 11 feet high, believed to belong to the Clinton. As is usual along the headwaters of Swan creek, the lower and middle parts of the Clinton are heavily bedded and free from chert. While chert occurs at various localities in the lower part of the Clinton, as already noted, this is rather exceptional. The bluff mentioned is on the W. D. Aydlott property, about a quarter of a mile south of the road crossing the creek east of the mines. The Black shale is immediately above the Clinton, but the base of the latter is not seen. About a mile north of the Lewis County line, on the east side of the creek, west of the home of Anderson Morris (locality 30), the Black shale rests on 26 feet of Clinton limestone. The base of the Clinton is not seen. The upper 2½ feet of the exposure consist of fossiliferous cherty beds, below which are 6½ feet of limestone with the chert in the form of layers of nodules. A layer containing *Heliolites* rather abundantly occurs immediately be-

neath, and under this, but best exposed a short distance southward, is white limestone containing very little chert. The thickness of this white limestone is at least 17 feet, but the base of the Clinton is not seen. The presence of considerable chert in the upper part of the Clinton section, accompanied by a comparative absence of chert in the lower part, is a feature often observed in the southern part of the area under investigation. While not a constant feature, it nevertheless frequently serves to give a clue as to the probable part of the Clinton section exposed. This may be verified by exposing the rest of the section by digging.

East of Palestine, on the east side of the creek (locality 31), the Black shale rests on 18 feet of Clinton, the upper 6 feet with chert nodules, the lower 12 feet more heavy bedded. East of the mouth of Little Swan creek (locality 32) the Black shale rests on 12 feet of heavy bedded Clinton. A third of a mile up stream (locality 33), 17 feet of Clinton are exposed beneath the Black shale, the lower beds being heavy bedded. Still farther up stream, about three-quarters of a mile below the crossing of the Natchez trace, and an equal distance beyond the last locality, the Clinton beneath the Black shale is only 4 feet thick. It forms a good quarry rock, and where freshly exposed shows a light blue color and a dense grain. Above Gordensburg the Silurian is absent, and the Black shale rests on the Ordovician.

CONTRAST OF VARIATIONS IN THICKNESS OF SILURIAN SUBDIVISIONS

Where the various subdivisions of the Silurian are overlaid by the Devonian they usually vary considerably in thickness. This variation in thickness generally consists in a rapid diminution toward the margin of outcrop along the flank of the anticline. Considering the gradual variations in thickness of these subdivisions where overlaid by higher subdivisions of the Silurian, their rapid diminution in thickness where no longer overlaid by higher Silurian formations is very striking. Since all of the subdivisions of the Silurian are affected in this manner, a considerable section often disappears within a very short distance (figures 1, 3, 4, 5).

At Bledsoe (locality 3) the Silurian section is 151 feet thick, but no trace of it is seen at the Gap of the ridge, 9 miles eastward. This is a decrease in thickness of about 17 feet per mile. Between the S. R. Wood locality (locality 2) and the Gap, however, the rate of decrease is about 30 feet per mile, while the indications are that between the Halum P. Weeks locality (locality 1) and the Gap a Silurian section of 31 feet disappears within considerably less than a mile; and yet there is every reason to believe that the full section of Osgood clay shale is present at the Halum P. Weeks locality, and that this clay shale, where con-

formably overlaid by the Laurel limestone, is increasing instead of decreasing in thickness eastward. Moreover, the Laurel limestone, which has been gradually increasing in thickness from Newsom northeastward, as far as Bledsoe, is only 18.5 feet thick at the S. R. Wood locality, and disappears a short distance east of Weeks' house.

At Baker 17½ feet of Louisville limestone disappear in a distance of half a mile southeastward.

There is no diminution in thickness of the Laurel limestone between Newsom (locality 12) and the Johnson V. Linton locality (locality 15); on the contrary, there is a slight increase. Nevertheless, in a distance of 2 miles southward the entire Laurel section, the equivalent of the Osgood bed, and the upper parts of the Clinton limestone have disappeared. This is estimated to be a decrease in thickness of 25 feet per mile. Between the J. Linton, Jr. (locality 16), and the J. Linton, Sr. (locality 17), localities, the Clinton diminishes from 16.5 to 2 feet in three-quarters of a mile. The rate of diminution between Newsom and the J. Linton, Sr., locality is 14 feet per mile. Between the locality 2 miles west of Tank (locality 14) and the W. M. Forehand (locality 13) locality, however, it is calculated to be at least 40 feet per mile, involving all the formations below the Waldron shale horizon. In striking contrast with this is the comparative constancy in thickness of the Laurel and Osgood sections at numerous exposures between Newsom and Pegram, also in an east and west direction although farther northward.

Near Fly (locality 19) the Silurian section diminishes about 70 feet in one mile going southward; east of C. E. Harris' it diminishes about 30 feet, and east of Mat Sowal's, about 40 feet per mile.

Between Montgomerys mill (locality 27) and Centerville (locality 25), in a distance of about 6 miles, the Laurel limestone seems to diminish in thickness from 28 feet to 25 feet. This is of very little significance, when the difficulty of discriminating between the top of the Osgood bed and the base of the Laurel limestone in these southern sections is considered. In striking contrast with this regularity in thickness is the almost entire disappearance of the Laurel limestone within a distance of 3 miles, if the 2 feet of limestone immediately beneath the Black shale at Tan Yard hollow (locality 22) be accredited to the Laurel horizon. If this identification is not correct the Laurel has entirely disappeared. In a distance of 6.5 miles between Centerville and Fogg (locality 20), all except the lower 5 feet of the Clinton have disappeared. This is a diminution of about 10 feet per mile. This rate of decrease is, however, much exceeded toward Sam Turner's house (locality 24), where the rate is about 40 feet per mile. Between Tan Yard hollow (locality

22) and the Mrs R. C. Orman (locality 23) localities the rate of decrease is calculated to be about 25 feet per mile.

In contrast with the pronounced changes in thickness noted above, where the Silurian formations are unconformably overlaid by the Devonian, note the comparatively small rate of change where the same subdivisions are conformably overlaid by higher beds of the Silurian. The greatest change in thickness noted in the case of the Clinton limestone is that between Whites Bend (locality 8) and Baker (locality 6), a decrease of 12.5 feet in 15 miles, or less than 1 foot per mile. The greatest change in thickness noted in the case of the Osgood bed is that between South Tunnel (locality 4) and Bledsoe (locality 3), a change of 16.5 feet in 14 miles, or slightly more than 1 foot per mile. Usually the rates of change per mile of the Silurian formations where overlaid by other Silurian beds are much less than those mentioned above.

EVIDENCE BY SILURIAN FORMATIONS AS TO AGE OF CINCINNATI ANTICLINE

Silurian overlaid by Devonian beds.—The preceding observations make it clear that along the western flank of the Cincinnati anticline the Devonian Black shale is deposited on the inclined margins of the various subdivisions of the Silurian. In correlating the data obtained in Tennessee and Kentucky it is evident that the Cincinnati anticline was considerably developed before the deposition of the socalled Corniferous limestone and of the Black shale. This brings up the question, What relation has the thinning of the various subdivisions of the Silurian along their margins on the western flank of the anticline to the history of the latter's development?

In this connection it should be noted that the very rapid thinning of the various Silurian formations is confined to those areas which are nearest the axis of the anticline, where these beds are overlaid by the Devonian. If the same formations be traced where they are overlaid by other Silurian rocks, they are found either to be fairly constant in thickness or to vary at a much smaller rate. Moreover, in northern Tennessee the Osgood and Laurel formations, when traced beneath other Silurian beds, gradually increase in thickness toward the anticline for a distance of many miles, but where overlaid by the Devonian they rapidly become thinner, and disappear within a very short distance on being followed in the same direction.

These differences in the variations of thickness of Silurian formations where overlaid by the Silurian and where overlaid by the Devonian suggest differences of history. While those parts of these formations which are overlaid by other Silurian beds are probably preserved in the form in which they were originally deposited, without any alteration in thick-

ness due to subsequent erosion, it is not probable that this was the case where the same formations are found directly overlaid by the Black shale.

This becomes more evident when the demands of a contrary view are considered. If the thinning of the various Silurian formations be due to original deposition, the thinned margins of these formations must represent their extreme limit of deposition on the western flank of the anticline. In that case it will be noted that at many points the boundaries of several formations occur within a very short distance of one another. Since no case is known in which the margin of an upper Silurian formation extends beyond the margin of a lower formation of this age, it is evident that not only must the Silurian beds have been deposited during a rise of the anticline, but the rise must have been so constant that at no point in the entire field was it possible for any of the Silurian formations to extend beyond the margin of one of the older Silurian beds. When the near approach to one another of the marginal outcrops of the various Silurian formations at many points is considered, the absence of overlap becomes marvelous, and the possibility of this being due to original deposition incredible.

If the present thinning of the subdivisions of the Silurian toward the axis of the anticline be due to original deposition, the western flank of the anticline must at some points have been strongly inclined, since in no other manner would it be possible to find such a thick Silurian section so near to the most eastern edge of outcrop of this age as is found at those localities where the rate of thinning is most rapid. It seems impossible to believe that no evidences of shore conditions would be found on a shore so highly inclined. Nevertheless not a single Ordovician fossil has so far been found included in Silurian rocks, although Ordovician forms are known at various points in Kentucky and Tennessee in the base of the Black shale and in the base of the Devonian limestone where these strata directly overlie or are closely contiguous to Ordovician rocks. No pebbles or ripple-marks or strong lithological changes are noticed pointing to the immediate vicinity of a shore line. The amount of admixture of clayey material in the Laurel bed is much less than might be expected if the Cincinnati anticline was already as well developed in the Silurian age as in times immediately preceding the deposition of the Devonian limestone and the Black shale.

Moreover, it seems hardly probable that such a rapid decrease of the Silurian beds toward the anticline could take place where these strata are overlaid by Devonian rocks without being accompanied by corresponding changes in thickness of these beds where covered by strata of the same general age.

In other words, the facts so far accumulated indicate that the thinning of the various subdivisions of the Silurian is not due to lack of deposition, but to subsequent erosion. They suggest that these subdivisions once extended much farther up the western flank of the anticline. A similar series of observations in central Kentucky indicates that the corresponding formations once extended also much farther up on the eastern flank of the anticline. In central Tennessee there is no evidence to show whether these subdivisions once extended entirely across the axis of the anticline, but in Kentucky and northern Tennessee there are some reasons for believing that at least the lower subdivisions—the Clinton and the Osgood beds—once were continuous across the axis of the fold.

The Cincinnati anticline was certainly fairly developed at the time of deposition of the so-called Corniferous limestone of Kentucky, and of the Pegram bed in Tennessee. Facts so far accumulated in Tennessee do not demand the existence of this anticline in Silurian times before the close of the deposition of the Louisville limestone. The anticline may have existed during Silurian times, but the proof has not yet been secured.

Since the elevations of all of the localities are not known, the sections of figure 5 are so drawn that the horizon at the base of the Black shale forms a horizontal line. It is believed that this will give a better idea of the character of the Silurian sections in times immediately preceding the deposition of the Black shale than would be given by any other method possible with the data at hand.

Silurian overlaid by other Silurian beds.—The facts given in the preceding pages indicate that the absence of the Clinton limestone in the region immediately west of Lafayette is due to pre-Devonian erosion. The rapid thinning of this limestone on passing from Whites Bend to Lafayette (figure 3), however, suggests that not far east of Lafayette there may have been a region where the Clinton was never deposited. Since an area northeast of Lafayette would lie along the axis of the Cincinnati anticline, this is equivalent to stating that the Clinton may never have been deposited over a part of the Cincinnati anticline. This at once raises the question whether the Cincinnati anticline had begun its development in early Silurian times, and therefore was already sufficiently developed in the Clinton period to prevent the deposition of the Clinton limestone. Various writers have held this view, their data being derived chiefly from more northern regions. In Tennessee the only instance of thinning of the Clinton limestone toward the anticline is that just mentioned. Present observations indicate a fair degree of uniformity in the thickness of this limestone in the more southern part of the area so far examined, south of Whites Bend, as far as Maury county.

In the absence of further evidence, the thinning of the Clinton limestone northeastward, toward Lafayette, deserves special consideration. In this connection it should be noticed that the thinning of the Clinton limestone, as above indicated, takes place in a direction very nearly parallel to the trend of the western flank of the anticline. Moreover, the rate of thinning is more rapid between Whites Bend (locality 8) and South Tunnel (locality 4), where the direction is northeast, than between South Tunnel and the localities west of Lafayette (localities 1 and 2), where the direction is more nearly east; in other words, more directly toward the crest of the anticline. From this it is just as easily possible to arrive at the conclusion that the area of non-deposition lay during Clinton times toward the north of South Tunnel and Lafayette, along the Tennessee-Kentucky boundary or northward, as to suppose that the axis of elevation of this Clintonless area coincided with that of the Cincinnati anticline, being in fact an early stage in the development of that axis.

Moreover, the Clinton is known to decrease in thickness on passing from southern Ohio to southern Indiana and adjacent Kentucky; in fact, it is entirely absent in some of the more western Silurian sections in Indiana, and is less than 3 feet thick in many parts of Indiana and adjacent Kentucky.

From this it appears fully as likely that an area of shallow waters, with possibly occasional limited land areas, existed in Clinton times in a region distinctly west of the axis of the anticline as that such an elevation existed along the present axis of this fold.

The thickening of the Osgood clay shale, and, to a less degree, also of the Laurel limestone, along the line from Whites Bend to Lafayette (figures 1 and 3) directly opposes the idea of the early development of a permanent fold along the present trend of the Cincinnati anticline; especially since the thickening of the Osgood and Laurel beds is more rapid where the direction is eastward, between South Tunnel and Lafayette, than where the direction is more parallel to the trend of the axis, between Whites Bend and South Tunnel. It is scarcely in keeping with the idea of the early development of the Cincinnati anticline that these two formations should thicken toward the anticline.

The Waldron shale is nearly uniform in thickness from the Harpeth River valley northward. The thinning of this formation along Duck river appears to have no relation to the Cincinnati anticline. The formation has not been recognized at all in the Tennessee River valley.

Since the Louisville limestone, in the area investigated, is everywhere overlaid unconformably by Devonian rocks, it is impossible to determine what were its original variations in thickness.

The only Silurian formation which varies considerably, lithologically, is the Osgood bed. This changes from an impure limestone to a clay shale on approaching the northeastern part of the area under investigation. In central Kentucky it appears as a clay bed both west and east of the anticline, the thickest exposures being east of the same. If this is due to the presence of the anticline in Osgood times, the evidence is not clear. Studies of the Osgood bed in central Kentucky (not yet published) indicate that the Osgood formation once extended entirely across the fold in that area.

Professor Safford's observations.—Since the area under investigation in Tennessee was studied by Professor Safford during many years and he never seems to have changed his opinions from those first expressed in his Geology of Tennessee (1869), the few references in his book to the problem of the Cincinnati anticline are here quoted: *

"By far the most important elevation of the strata in middle Tennessee was the wide dome, the decapitation and denudation of which have given us the Central basin.

"This dome-like elevation of middle Tennessee is sometimes associated with a similar elevation of strata further north, within an area divided among the states of Kentucky, Ohio, and Indiana. The city of Cincinnati is about the center of this area. The elevation in Tennessee and that in the Cincinnati area doubtless occurred at the same time, and are perhaps parts of a single line or axis of elevation extending from Tennessee to Ohio. The elevation, however, was greater in the Cincinnati and Tennessee parts than in the intermediate portion. This line of elevation is sometimes called the Cincinnati axis.

"Along the eastern escarpment of the Central basin, from the Kentucky nearly to the Alabama line, the Black shale rests on the Nashville formation, without any intervening rock.

"On the western escarpment this is also the case at a few points, but generally a Niagara bed has appeared to separate the two, bearing above it here and there a trace of the Lower Helderberg. The Niagara and Helderberg strata are unconformable to the Nashville, and never covered the dome of the basin."

Professor Safford was of the opinion that the Clinton did not occur on the western side of the anticline. All of the Silurian formations discussed in this paper were referred by him to the Niagara. His type sections are found along the valley of the Tennessee river, in western Tennessee, and since in that region the sponge *Astræospongia meniscus* occurs in considerable abundance in the equivalent of the Louisville formation, he applied the name "Meniscus limestone" to the entire series. This will explain why the most eastern outcrops of Silurian rocks west of the anticline are referred by him to the Meniscus limestone rather than to the "Dyestone group," Safford's name for the

* Pages 148 and 291.

Clinton of eastern Tennessee. This will make clear also the following quotations: *

"Upon entering the Central basin from the east, the featheredge of the Meniscus limestone is met with on the northern side, in Macon county, and on the southern, in Lincoln, and in the southwestern part of Bedford.

"The (Meniscus) series is divided into two nearly equal members, the sponge-bearing bed above and the variegated bed below.

"It is the upper member of the Meniscus formation, for the most part, that appears on the slopes of the Central basin; the variegated bed presents itself mainly in the Western valley and in its ramifications."

The sponge referred to is the *Astræospongia meniscus.*

It is evident that Professor Safford was of the opinion that the Cincinnati anticline was in existence already in Silurian times, since he states that the Niagara and Lower Helderberg are unconformable to the Nashville beds, although he nowhere offers any reason for believing in this unconformity. The problem of a possible unconformity between the Ordovician and Silurian still remains to be solved by some investigator.

Professor Safford appears also to be of the opinion that the upper beds, consisting of the Meniscus or sponge-bearing beds, overlapped the lower or variegated beds, and hence were more commonly exposed on the western slopes of the Central basin. He probably held the idea that the anticline was sinking during Silurian times, and that on this account the upper beds progressively overlapped the lower ones. It may be seen, however, from the accompanying map and sections, that the equivalent of the sponge-bearing bed, the Louisville limestone, is by no means as frequently exposed, nor does it extend as far eastward up the anticline in its present condition as the equivalents of the variegated beds—the Laurel, Osgood, and Clinton beds of this paper.

In the Elements of the Geology of Tennessee, by Professor Safford and Doctor Killebrew, the name "Clifton limestone" was adopted for that of the Meniscus limestone. Even at the type locality this limestone includes all of the horizons from the Clinton to the Louisville, except the Waldron shale, which has not been identified in the western valley of the Tennessee river.

SILURIAN EXPOSURES ON THE UPPER CUMBERLAND, SOUTHERN KENTUCKY

The eastern border of the area along the crest of the Cincinnati anticline within which no Silurian rocks are preserved can not be determined with certainty in Tennessee, since no outcrops occur in those regions where this border must be sought. It may be located, however, east of

* Page 313.

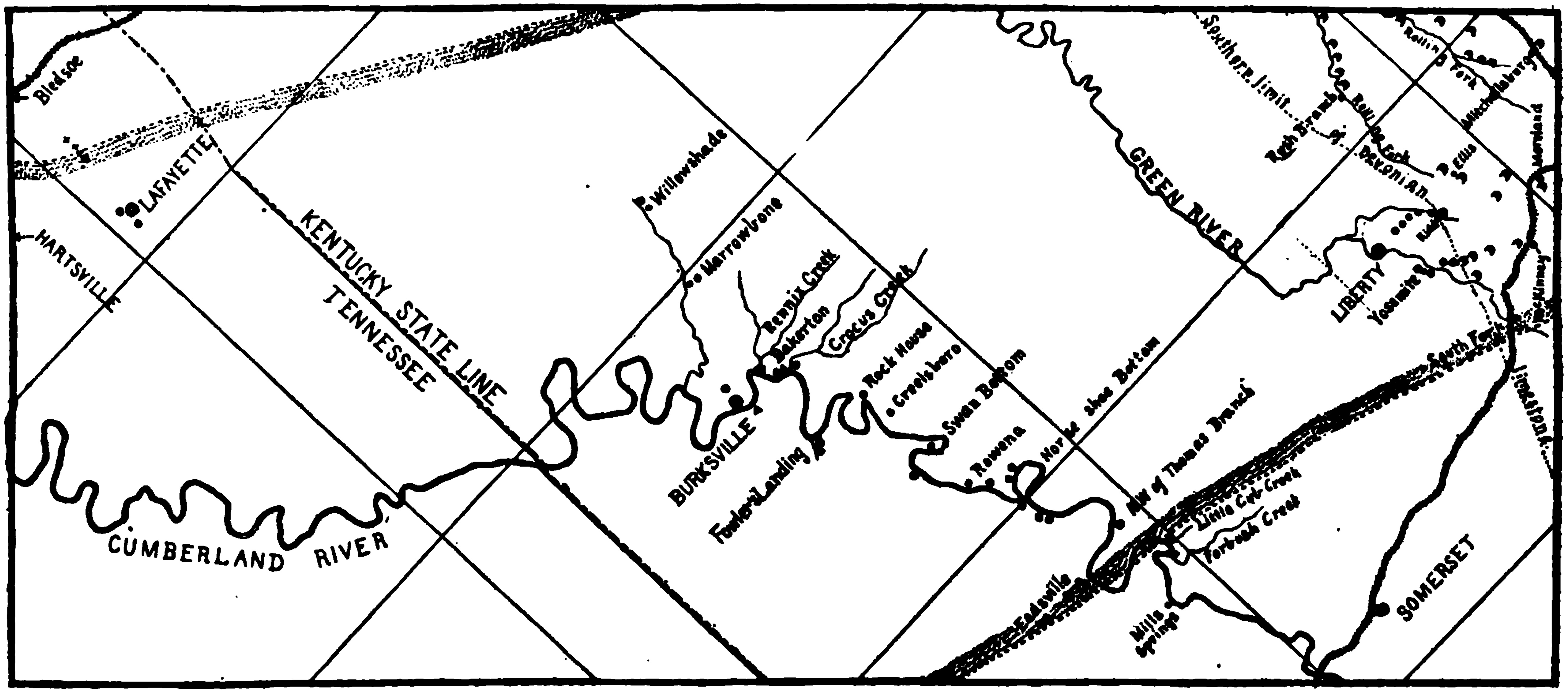


Figure 6.—*Sketch Map across Cincinnati Anticline along Cumberland River, Kentucky.*

The western limit of outcrop of the Silurian rocks on the east side of the anticline is indicated by a dotted line with a band of dots on the western side. Localities where the Devonian limestone rests directly on the Ordovician are indicated by the letter D with its center blackened. Outcrops of the Fowler limestone along the Cumberland river are indicated by triangular figures with the centers blackened. Other devices as in figure 1.

the anticline where it crosses the upper waters of the Cumberland river, in southern Kentucky.

While passing down the Cumberland river with Professor Arthur M. Miller, of the State College of Kentucky, we found two exposures of Silurian rocks west of Mill Springs (figures 6 and 7).

About a quarter of a mile up Forbush creek a small stream enters from the north. Here 15½ feet of Silurian limestone occur below the sandy layer at the base of the Black shale. A layer with large crinoid beads occurs 21 inches below the top of this limestone, and north of the mouth of Forbush creek, near the house of William Richardson, the same layer is found, including *Whitfieldella cylindrica*, variety *subquadrata*.

At the mouth of Little Cub creek the Ordovician is overlaid by Silurian limestone, with clayey shales farther up. The limestone at the base is 19 feet thick. The layer with large crinoid beads and *Whitfieldella cylindrica*, variety *subquadrata*, occurs 3½ feet below the top of this limestone. Overlying the limestone are 2½ feet of greenish clayey shale, 2 feet of clayey limestone, and an interval of 9 feet probably occupied entirely by greenish clayey shale.

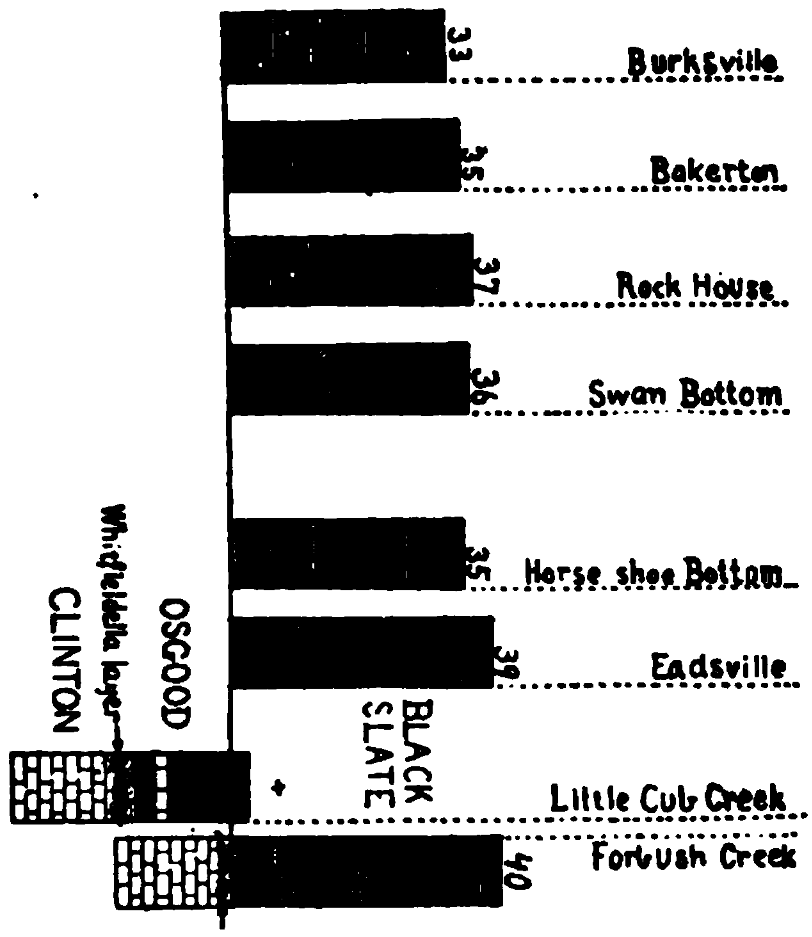


FIGURE 7.—*Sections of Chattanooga Black Shale and Silurian Rocks.*

Along Cumberland river, Kentucky.

At both localities the large crinoid beads belonged originally to the Clinton. The Clinton was probably eroded, and the crinoid beads were accumulated in the residual beds. The Whitfieldella associated in the same bed is a characteristic form of the Osgood bed. It differs from the typical forms of *Whitfieldella cylindrica* only in its more grandrangular outline and its less sinuate anterior margin. The limestone below the Whitfieldella layer is referred to the Clinton. The limestones and clays above the crinoid bed are referred to the Osgood. The subject has been more fully studied in corresponding beds in central Kentucky, east of the anticline.

Outcrops of Clinton limestone and of the Whitfieldella layer frequently contain little pockets of oil in the southwestern part of Madison county, Kentucky, and at various points northward. According to Professor Miller, it seems that the source of the oil in Bath and Rowan counties,

near Salt Lick, along the Licking river, is in the horizon of the Clinton limestone and the immediately overlying Osgood rock.

Devonian Formations

DEVONIAN LIMESTONE ABSENT ALONG CUMBERLAND RIVER, KENTUCKY

The Devonian limestone is absent along the Cumberland river, and for some distance northward in central Kentucky.

The most southern outcrops of the Devonian rock in Kentucky extend to within about 10 miles of the westward course of the Green river across the crest of the Cincinnati anticline (figures 6 and 8).

Figure 8.—*Southern Limit of Devonian Limestone.*

This sketch map shows the approximate southern boundary of the Devonian limestone in the region of the Cincinnati anticline, in central Kentucky.

It is absent north and northeast of Liberty and along the valley of the Cumberland river in Kentucky. It is probably absent also along that part of the Cumberland river which passes through Tennessee, although this region has not been investigated east of Lafayette. A doubtful rock occurs at the S. R. Wood locality (figure 1, locality 2) west of Lafayette, and 10 miles north of Hartsville. The base of the fissile Black shale is here underlaid by 6 to 16 inches of dark, earthy rock. The upper half of this rock is phosphatic, and the lower half includes numerous fragments of silicified brachiopods and crinoid stems. Crinoidal material occurs also at the base of the Black shale at the Gap of the Ridge, less than two miles eastward. Since it was impossible to determine the specific identity of any of this fossiliferous material it is impossible to

state definitely whether it is residual Ordovician material taken up into the base of the Black shale or Devonian material poorly preserved.

It probably, however, corresponds with the millstone rock of Professor Safford, and this is said by him to contain Nashville (Ordovician) fossils. In that case it is probably residual material included in the base of the Chattanooga Black shale.

The following lines, copied from the report of Professor Safford,* give his account of the millstone rock:

"In Sumner county, a few miles north of Hartsville, immediately below the Black shale, is a bed, from which *millstones* were formerly extensively manufactured. This bed is a mass of shells, closely packed, and silicified. The bed is several feet thick, and contains Nashville species. The shells are so packed as to make the rock, in due degree, cellular. The weathered portions, near the outcrop, are preferred, for the reason that, within, the spaces between the shells are filled with calcareous matter, which, by exposure, is leached out. The millstones manufactured here, were highly esteemed. I do not know that any have been made of late years (1869)."

THE PEGRAM LIMESTONE

In the valley of the Harpeth river (figures 1 and 2), between Newsom and the bridge west of Pegram, all exposures of the Louisville formation are overlaid by Devonian limestone—the Pegram limestone.

Its thickness increases toward the west. At Newsom (locality 12) it is 3 feet thick. Blocks of this stone occur west of the quarry nearest the station, above a negro hut on the south face of the hill (plate 40, figures 1 and 2). It occurs also three-quarters of a mile west of Foster and Creighton switch, along the river southeast of Sam Walker's house. Near the eastern end of the bluff, the Laurel, Waldron and Louisville beds are well exposed. Overlying the latter is the Devonian limestone, 5 feet thick, covered at some points by 4 inches of sandstone or of sandy limestone (locality 10).

Possibly the 3 inches of sandy rock at the top of the Laurel limestone south of Johnson V. Linton's house (locality 15) belong to this horizon.

At the bridge a mile and a half west of Pegram (locality 9) the Devonian limestone is 8 feet thick at the most eastern exposure along the railroad (plate 41, figures 1 and 2). At its most western exposure, in the quarry north of the railroad, the total thickness is 12 feet. The upper 6 inches of the white Devonian limestone contain small black pebbles, usually less than half an inch thick. Similar pebbles occur at the top of the Devonian limestone in many parts of southern Indiana and Kentucky.

---

* Page 283.

The Devonian limestone in the Harpeth River region is usually very white and crystalline. At the bridge west of Pegram this white limestone is overlaid by 6 to 12 inches of dark earthy rock, and above this lies the Black shale. The white limestone seems to pass gradually into this earthy rock. *Camarotœchia carolina*, *Tropidoleptus carinatus*, and *Spirifer pennatus* have so far been found only in the earthy layer. *Nucleocrinus verneuli* occurs at various levels in the white limestone. The other fossils mentioned in the list given at the close of this paper (see page 437) are found near the top of the white limestone. As far as may be determined at present, the top of the Pegram limestone corresponds to the Sellersburg limestone of Indiana, and to the Hamilton of New York, while the lower part indicates at least one characteristic Corniferous fossil.

In central and northern Kentucky the Devonian limestone rests on successively higher subdivisions of the Silurian, on ascending the flanks of the anticline. In the Harpeth River region of Tennessee it is known only where resting on the Louisville limestone, but it appears to rest on lower beds of this limestone at Newsom and Sam Walker's than at the bridge west of Pegram, as far as can be judged by the absence, at the eastern localities, of the fossiliferous Louisville beds discovered near the bridge.

THE CHATTANOOGA BLACK SHALE

Variations in thickness.—Although the Devonian limestone of Kentucky thins out and disappears a short distance south of the central part of the state, an equivalent of this limestone is known in Tennessee, but it has so far been found only in one limited area—in the valley of the Harpeth river.

The Black shale, however, has a much more general distribution. Although the Black shale also thins out southward, it disappears entirely at but few points.

Along the valley of the Cumberland river, between Mill Springs and Burksville (figures 6 and 7), the Black shale decreases from 40 to less than 35 feet. West of Lafayette, in northern Tennessee, the thickness varies usually between 25 and 30 feet, but the thickness is much less constant here than east of Burksville. At the spring southeast of Lafayette, for instance, the Black shale is only 13 feet thick, and west of Whites Bend, as already noted, it is reduced to 4 feet, and at a number of points is entirely absent.

Along the Harpeth river, west of Newsom, the Black shale is 20 feet thick. South of this river most exposures seem to vary between 5 and 8 feet. At numerous points in southern Maury county, in Lewis county, and in northern Giles county the Black shale is only 12 to 15 inches

thick. At some points in these counties the Black shale is entirely absent. One of these localities is that mentioned by Professor Safford: *

"At the foot of the 'big hill,' five miles from (southwest of) Mount Pleasant, on the Waynesboro road. Here the siliceous cherty layers [Waverly] rest directly on the Nashville rocks [Ordovician], and all intervening formations being absent."

Sandy and earthy layers at base of Black shale.—At the most eastern exposures on the Cumberland river, in Kentucky, a 3-inch layer of sandy rock occurs at the base of the Black Shale section. This layer may be traced westward down the river, and is phosphatic. Between Rowena and Creelsboro that part of the formation which immediately overlies the basal sandy layer is more earthy and less shaly. Its thickness varies usually between 2 and 3 feet, but thicknesses of even 6 feet are locally recorded. Instead of this brownish rock, a greenish, more shaly rock appears at various points between Swan Bottom and Burksville. Sometimes only the lower part of the brownish rock is replaced by the greenish, more clayey layers. Since both the brownish rock and the greenish, more clayey rock weather away more readily than the overlying Black shale, the base of the Black Shale sections exposed by the steep cliffs along the Cumberland usually recedes a little.

In Tennessee both the sandy layer and the brown, more earthy layers at the base of the Black Shale section occur. The brown layers, breaking up into irregular fragments, are well seen in the South Tunnel and Pegram sections. The sandy layer is seen also near John Suell's house, west of Whites Bend, in the quarry near the road. Along the hillside southwest of Newsom station this sandy layer is fossiliferous. At many points in Maury county it contains minute gasteropods resembling forms (*Microceras* and *Cyclora*) found in Ordovician rocks.

Phosphatic character of base of Black shale.—At many points south of the Cumberland river, a dark blue, fine grained, very phosphatic rock takes the place of part or all of the brownish rock occurring at the base of the Black shale in the Cumberland River sections of Kentucky. At the bridge west of Pegram there are only 8 feet of the typical fissile black shales, and these are overlaid by the nodules which mark the top of the Black Shale formation at so many points in Kentucky and Tennessee. Beneath these shales are found 11 feet of more earthy rock, breaking up into irregular fragments. At the base are 14 inches of dark, fine grained phosphatic rock—the "black phosphate" of southern Tennessee.† This is the most northern recorded occurrence of the typical phosphate rock. It contains numerous specimens of *Lingula spatulata*.

* Page 332.

† Charles Willard Hayes: The Tennessee Phosphates. 17th Ann. Rept. U. S. Geol. Survey, 1896.

The phosphate rock varies considerably in thickness, even in localities in the same neighborhood. In a general way it increases toward the southwest, and was, until very recently, quarried at many points in Hickman and Perry counties. It appears to take the place, at some points, not only of the earthy brown beds at the base of the fissile black shales, but even of the fissile shales themselves. This, according to Professor Safford, is especially true of some of the exposures in Hardin and Wayne counties. It should be remembered, however, that the fissile black shales diminish considerably in thickness in southern Tennessee, irrespective of any change in thickness in the phosphate rock.

North of Mount Pleasant the nodules at the top of the Black Shale section are found 12 inches above the coarse sandstone which forms the base. This leaves only a thickness of one foot for the fissile black shales. Half a mile northeast of Lynnville the fissile black shales do not exceed 1 foot in thickness. At Dodsons station, north of Lynnville, the fissile shales are 12 to 15 inches thick, and at one locality west of the station are underlaid by a little sandy phosphatic rock.

Erosion of Black shale during early deposition of the Waverly.—South of Rockdale the upper part of the fissile black shale loses its fissile character. For instance, half a mile above the Oliver Williams house, in the Cook hollow, the base of the Black shale consists of coarsely sandy rock overlaid by 28 inches of phosphate rock, 2 feet of fissile black shale, and 3 to 4 feet of much less fissile shale, black below, becoming greenish toward the top. Half a mile up the old Saw Mill hollow, also called the Rattlesnake hollow, the conglomeritic sandstone, 6 inches thick at the base of the section, is overlaid by 16 inches of dark phosphate rock; the fissile shales are absent; immediately above the phosphate rock occur 3 feet of a very fine-grained rock, not fissile, containing traces of *Chonetes* and of other fossils. In the gully southeast of the Oliver Williams house the base of the section consists of a dark, sandy, partly conglomeratic rock 18 inches thick. Both the Black shale and phosphate rock are absent. Immediately above the conglomeratic rock occur 11 inches of light green clayey rock containing purple brown phosphatic material, both in the form of small, irregular particles and of nodules. Above this are found 8 inches of crinoidal, greenish rock, with fish teeth. At the "Big hill," immediately westward, on the road to Waynesboro, the entire Black Shale section is absent.

The purple brown phosphatic material found immediately above the conglomeratic, sandy rock at the Oliver Williams locality resembles the material forming the phosphatic nodules at the top of the Black Shale section in most parts of Tennessee and Kentucky. The fish teeth appear to belong to the same horizon as the bed from which the phos-

phatic material was obtained. The greenish clay material, however, belongs to the Waverly horizon, so that the base of the Waverly appears to contain material derived from the eroded top of the Black Shale bed. The crinoidal material is unquestionably of Waverly age. The fine-grained but not fissile rock in the old Saw Mill hollow may also be of Waverly age, since species of *Chonetes* of the same general form are rather common at the base of the Waverly section in the northern part of Giles county. The dark color of the rock may be due to carbonaceous material received from the denuded Black shale of this area, while the more sandy character may be due to material washed in from some other source by the Waverly sea. The gradual passage of the black rock upward into the greenish rock, as already described, is also favorable to the view that the black rock, without good fissile cleavage, may be of Waverly origin. In case these observations are correct, the absence of the Black shale at the "Big hill" may be due, not to original lack of deposition, but to subsequent erosion.

Cause of thinness of Black shale in southern Tennessee.—So far as may be determined from the sections studied, the Black shale diminishes in thickness on passing from the most eastern exposures on the Cumberland river southwestward to the Harpeth River region of Tennessee. Southwest of the latter stream this diminution is even more considerable and is quite general. An entire absence of Black shale is noticed not only at the Big Hill section in the southern part of Maury county, but also at various points in the eastern part of Lewis county, along Helm fork, Bell branch, and northwest of Lucerne.

A study of the Silurian-Devonian unconformity in Tennessee indicates that the Cincinnati anticline had begun its development before the deposition of the Black shale. Its trend may be determined across the central part of the state. At its southern end it appears to have turned more distinctly westward, and it is at this southern end of the Cincinnati anticline that the thinnest sections of the Black shale or the cases of its entire absence occur. The question may therefore be raised whether this thinning of the Black Shale section in southern Tennessee is due to a marked development of the southern end of the Cincinnati anticline at the time of the deposition of the Black shale and the base of the Waverly.

Source of the detrital material at base of Black shale.—There is also an increase in the coarseness and often in the thickness of the sandy and earthy material at the base of the Black Shale section on passing from the most northeastern localities along the Cumberland to regions west of the anticline in southern Tennessee. This coarseness becomes sufficient in many parts of Maury and Hickman counties to form a sort of

conglomerate. This suggests a southern source for the sandy and conglomeratic material.

CAUSE OF EROSION SHOWN AT THE SILURIAN-DEVONIAN CONTACT

In the preceding pages it has been shown that the Devonian limestone and, especially, the Devonian Black shale rest on the inclined edges of the various Silurian formations. Reasons have been given favoring the view that these subdivisions once extended much farther up the flanks of the anticline, but were eroded before the deposition of the Black shale and of the Devonian limestone. It would be interesting to know whether this erosion was due to marine or subaerial causes. The number of facts known at present is inadequate to determine this matter. The Devonian limestones are of marine origin, and their basal layers in Kentucky and Tennessee are not known to give any indication of residual soils or any other evidence of land conditions. Since the Silurian-Devonian erosion must have taken place before the deposition of the Devonian limestones of Kentucky and Tennessee, the general absence of evidence of subaerial erosion at the base of the Devonian limestone is important, although the general absence of marine rocks between the Louisville limestone and the middle Devonian limestone along the flanks of the anticline slightly favors the view that land conditions were present.

In the case of the Black shale, the evidence of land conditions or of fresh-water conditions is more favorable. At many points through its entire extent it has retained remains of land plants. Its strongly carbonaceous character, which gives rise to the black color of the shale, does not necessarily indicate the presence of land plants, although the presumptive evidence is in favor of this view. At various localities the remains of animals have been preserved in this shale. Some of the brachiopods, such as species of *Lingula*, *Barriosella*, *Schizobolus*, and *Orbiculoidea* may have lived in brackish waters, and these are the forms usually found in Kentucky and Tennessee. They occur usually only near the base of the formation, but in northern Indiana near Delphi, an undoubted marine fauna, including species of *Goniatites* and *Orthoceras* has been discovered by Mr E. M. Kindle. This fauna occurs within 20 feet of the base of the Black shale. This is quite near the base when the total thickness of the Black Shale deposits of northern Indiana is considered. As a rule, however, it may be stated that evidences of marine life are absent in the Black shale except at the base.

The base of the Black shale is often decidedly earthy and is often also phosphatic. It is well known that the base of Black shale is in many parts of southern Tennessee sufficiently phosphatic to be worked as a phosphate rock. One of the theories of the accumulation of the phosphatic

material at this horizon is that it was derived from the phosphatic material included in the shells of the underlying Silurian and Ordovician rocks; that it is an accumulation in one sense of residual material.

This sandy base of the Black shale occasionally incloses fossils derived from the underlying formations. The sandy material itself is probably of residual origin. It may represent a residual soil, but the evidence is again inconclusive.

The fissile black shale is composed of particles so light that they could have easily been blown by the wind. The remarkably fine-grained character of the fissile shales, the entire absence of coarser material except at their base, and their remarkably wide geographical distribution suggest that they may possibly consist of wind-blown particles, derived perhaps from many strata, from points far distant from one another. The absence of coarser detrital material suggests that the region of deposition was practically flat. The preservation of fragments of land plants indicates that it was probably a region of marshes. It may be imagined that the same particles traveled in many directions before finding a final lodgment. Marshes at one point may have dried up and the material accumulated in it may have again turned into dust, thus permitting the frequent shifting by the wind of the materials which now form the shale.

While all this may be readily enough imagined, it must not be forgotten that very few facts have so far been collected which have any bearing upon the solution of the problems involved.

Ordovician—Richmond Group

General Relationships

Observations on Silurian rocks so far made in Kentucky and Tennessee indicate that the Cincinnati anticline was in existence before the deposition of the Devonian limestone (Corniferous and Hamilton) and of the Black shale (Genesee and Portage), but do not give indubitable evidence of the existence of this fold in early Silurian times. It has been believed by some that the conglomerate in the Clinton near Belfast, in Highland county, Ohio, indicates the presence of this fold, or at least a beginning of its development, in late Ordovician or in early Silurian times. At one time the materials of this conglomerate were believed to have been derived from the Ordovician, but it is now known that they were derived from the immediately underlying beds belonging to the middle and upper parts of the Clinton.

It is possible that a detailed study of the Ordovician formations in the areas now occupied by the Cincinnati anticline may demonstrate a development of this fold in times even as early as the Ordovician. So

far studies in this field have been chiefly of a paleontological nature. The following notes are offered as a slight contribution to the subject:

THE LEIPERS CREEK BED, TENNESSEE

In the adjacent parts of Ohio, Indiana, and Kentucky the Richmond group is about 300 feet thick. Southward it becomes rapidly thinner, and was once believed to be entirely absent in central Tennessee.*

In the summer of 1899, while investigating the Silurian rocks of Leipers creek, in Maury county, Tennessee, the writer collected fossils from a rock which appears so different, lithologically, from the ordinary Ordovician rock of this region that it received special attention in a separate paragraph in the Geology of Tennessee by Professor Safford.†

> "On Leipers creek, at the 'Oil Spring' (Tom Fox locality of this paper, 18), in Maury county, and about half a mile below the Williamson line is another bed of marble. This is a gray crinoidal, and coralline rock, spotted with red, and having a flesh-colored appearance. Associated with it are other layers, with red, gray, and green colors. Slabs cut from these rocks and polished present a handsome appearance. The main bed is ten feet thick, and quite massive. This marble is at the top of the Nashville formation, and is followed, in ascending order, by the Niagara, which is here 50 feet thick; and this, again, by Black shale, 8 feet, above which is about 60 feet of the rocks of the silicious formation."

This so-called marble bed is well exposed northward for about a quarter of a mile, as far as the house of Carol Litton. Here it is seen to be overlaid by thin Ordovician clay shale.

The marble bed is also exposed at numerous points southward. It occurs a short distance northeast of Elam's store, about half a mile from Fly, forming the bed of the creek. It is here a salmon-brown rock, about 6 feet thick. It is overlaid by 1 foot of blue clay, 1 foot of limestone, weathered into thin pieces at the top, and 4½ feet of clayey material, all containing Ordovician fossils. Immediately above is the base of the Clinton, consisting of a white crinoidal limestone, with *Atrypa nodostriata*. The bed is exposed north of R. S. Elam's house, a quarter of a mile northeast of Fly.

South of Fly the bed rises above the valley of the creek, and about 2½ miles south, north of J. M. Gardner's house, is found near the top of the hill. The so-called marble layer is here crinoidal, richly fossiliferous, and about 9 feet thick. It is overlaid by clayey beds, with Ordovician fossils, and then by the conglomeratic layer at the base of the Black shale.

The fossils collected from the so-called marble and from the overlying clays were recognized by Mr E. O. Ulrich as Richmond Group fossils,

* Geology of Minnesota, vol. iii, part ii, 1897, section 9 in Introduction.

† Page 282.

and as being more strongly related to the Richmond Group fossils of the northwest, in the Mississippi valley, than to those in Ohio valley near Cincinnati.

The same layer is also specially noted by Professor Safford in his section of the rocks at Bakers station (locality 6) and in one of the following paragraphs, although the identity of this bed with the Leipers Creek bed is not established: *

"The top of this (Nashville formation) is seen some distance below Bakers station. The upper layer is red, very ferruginous limestone or dyestone; is fossiliferous, and 8 feet thick. Below this are the usual Nashville layers, highly fossiliferous.

"In the section last given a red, ferruginous limestone occurs. It is called dyestone by those living in the vicinity, and is used for dyeing purposes. The bed is here 8 feet thick. Some of it appears rich enough to be used as an iron ore. A few miles south or southwest of this point, in Davidson county, this or a similar bed of red calcareous rock, rich in iron, occurs. The hills containing it are of a deep red color. This rock resembles in some respects the dyestone of east Tennessee. It rests upon rocks of the Nashville formation, to which it is referred. Its fossils, however, although having a Lower Silurian (Ordovician) aspect, have not been carefully studied, and it may be found necessary hereafter to include it in the Niagara group, of which, in this region, it would then form the base. These remarks apply especially to the rock represented in the section."

This layer is exposed just above the spring at the south end of the first large quarry southeast of Bakers station. It is there about 4 feet thick, and is immediately overlaid by the Clinton. The fossils were identified by Mr Charles Schuchert as Richmond Group fossils. One of these, *Strophomena wisconsinensis*, again recalls the northwest relationship of this horizon.

Orthis proavita, found north of R. S. Elam's house, in the clay shale above the so-called marble, is another of these northwestern species. A variety of *Hebertella insculpta* with very fine striæ, *Dinorthis subquadrata*, and a very typical variety of *Platystrophia acutilirata* are found at the same locality. *Hebertella occidentalis* is rather common in the clay just beneath the Clinton near Carol Litton's house. The fauna is quite varied.

The Leipers Creek bed, including the limestones and clays carrying the Richmond Group fauna, occurs also at other points along the western side of the Cincinnati anticline. Similar beds are found near Fernvale Springs, and a dyestone layer is said by Professor Safford to occur on the waters of Harpeth river, in the southwestern part of Davidson county. The fauna appears to be widely distributed in the northwestern part of Maury county.

---

* Loc. cit., pp. 281, 282.

At South Tunnel about 8 feet of the layers near the top of the Ordovician appear contorted (plate 37, figure 1). What produced this appearance is unknown, the contortion affecting the middle parts of the layers without preventing a fair degree of evenness on their upper and lower surfaces. The same appearance is noted in the beds immediately beneath the Clinton west of Whites Bend (plate 39, figure 1). A lithologically similar rock occurs below the 4 feet of limestone belonging to the Leipers Creek bed at Bakers station. According to this, the equivalents of the marble in the Leipers Creek valley and of the dyestone at Bakers station will not be found at Whites Bend or at South Tunnel.

THE CUMBERLAND SANDSTONE OF SOUTHERN KENTUCKY

Origin of the name.—A group of nearly unfossiliferous rocks occurs in southern Kentucky, beneath the Black shale. They extend from the southwestern border of Pulaski county to the southern limits of the state, and were called by Professor N. S. Shaler the "Cumberland sandstone." The name sandstone is inappropriate, because the rock varies usually between a calcareous clay and a clayey limestone. Since the most eastern exposures of Ordovician rocks do not quite reach the Pulaski county boundary, it is evident that all practically unfossiliferous beds were included under this name.

These Cumberland beds and the underlying rocks were so much folded and eroded previous to the deposition of the Black shale that the same layers occur at different depths beneath the Black shale at different localities. There has also been much folding since the deposition of the Black shale.

The Fowler limestone.—Although the general mass of the Cumberland bed is practically unfossiliferous, there is one horizon at which fossils are fairly constant for a considerable distance. On account of its ready accessibility east of the store at Fowlers landing, on the side of the hill, it will prove convenient to refer to this horizon as the Fowler limestone.

About a mile above Burksville, on the south side of the river, in a gully which rises steeply eastward from a spring at the river's edge, the Fowler bed occurs 44 feet below the base of the Black shale. At the top is a layer of dense limestone 1 to 1.5 feet thick. Below is shaly bluish limestone 1 foot, with *Hebertella occidentalis*, *Pterinea demissa*, and *Ischyrodonta* near *elongata*. Beneath is a limestone layer with branching bryozoans. The bed occurs 110 feet above the river.

Just above the mouth of Rennix creek the Fowler bed occurs 56.5 feet below the Black shale. At the top is a dense limestone layer containing *Ischyrodonta* near *elongata;* below are 2 feet of dark shaly or

clayey limestone with *Hebertella occidentalis*, *Byssonychia robusta*, and *Pterinea demissa*. The bed occurs 33 feet above the river.

The cliffs immediately above Bakertown landing show near the top several feet of fossiliferous limestone belonging to the Fowler horizon. Passing up stream along the top of the cliffs, an open field shows many fragments of limestone from this bed, many of which are partly cherty and contain fossils. Among these Mr Ulrich identified *Ischyrodonta*, three forms, near *truncata*, *Isch. elongata*, and *Isch. decipiens*, *Byssonychia robusta*, *Lophospira bowdeni*, and *Bellerophon mohri*. The Black shale is not well exposed, but it seems to have occurred about 12 feet above this bed.

Above the mouth of Crocus creek the Fowler bed appears to be entirely absent.

At Fowler's landing, east of the store, and above the houses along the road leading away from the river, the Fowler bed occurs 21 feet below the base of the Black shale and 96 feet above the river. The layer of limestone at the top is very fossiliferous and contains *Hebertella occidentalis*, *Pterinea demissa*, a species of *Orthoceras*, and fossils identified by Mr E. O. Ulrich as *Isochilina* variety of *subnodosa*, *Modiolopsis* sp., *Ischyrodonta* near *Isch. truncata*, and *Glyptodesma gibbosa*. About 4 feet of limestone contain fossils, most of these being found in the top layer.

The Fowler bed appears to be absent at Rock House.

So far as may be determined from the few observations at hand, a synclinal fold once affected the Ordovician rocks in the neighborhood of the localities here cited. Its trough appears to have passed from the strong bend of the river, north of Burksville, near the mouth of Rennix creek, eastward. The Fowler bed seems to have been preserved in the trough of this fold and to have been removed along the flanks on the north before the deposition of the Black shale.

Beds above the Fowler limestone.—The greatest thickness of rock above the Fowler bed occurs at the mouth of Rennix creek, and consists of 56.5 feet of thin-bedded limestones. No fossils have so far been found in these limestones, but lithologically they bear no resemblance to the Silurian rocks on either side of the anticline along the Cumberland river, and are therefore considered as of Ordovician age. The name Rennix limestones may prove convenient for them.

Beds below the Fowler limestone.—Below the Fowler bed are usually at least 35 feet within which no fossils are known at any point. They consist of about 15 feet of thin-bedded limestone, 5 feet of thicker limestones, frequently with chert, and 15 feet of thin-bedded clayey rock.

Beneath these unfossiliferous rocks occur a considerable thickness of clayey rocks, very similar to those last mentioned. Their chief distinc-

tion from the preceding rocks consists in the fact that at many localities they become still more calcareous, owing to the presence of numerous fossils, chiefly large forms of *Platystrophia lynx* and occasional specimens of *Hebertella occidentalis.* At other localities, however, these fossils do not occur in the upper parts of these calcareous clays, or at least occur but rarely, and are difficult to find. Since these beds form the main parts of the Ordovician exposures as far east as Thomas branch, often forming steep cliffs, notwithstanding their clayey character, it is practically certain that at least the unfossiliferous parts of those calcareous clays were included in the original Cumberland sandstone section.

The richly fossiliferous blue Ordovician limestones, which are often present in considerable thickness in the Cumberland River valley, seem to belong about 100 feet below the Fowler limestone.

Equivalency of Cumberland sandstone and Madison bed.—The fossils collected in the Fowler horizon belong to the Richmond group. Several of them are especially common near the top of the group. The same fossils and closely related species have been found in the immediate vicinity of Moreland and also at several localities west of this station, in central Kentucky. At these localities they occur above a series of clayey limestones which are practically unfossiliferous. These clayey limestones weather more readily than the richly fossiliferous blue limestones beneath or the fossiliferous limestones above. They have been traced northwestward as far as the Ohio river. In the later reports of the Indiana survey they are called the Madison beds. There is no doubt that in southern Indiana and northern Kentucky the Madison beds are merely the upper unfossiliferous part of the Richmond group. There, as well as near Moreland, a few limestones with Richmond Group fossils immediately overlie the thicker, nearly unfossiliferous Madison Bed section.

Possibly a part at least of the unfossiliferous beds underlying the Fowler limestone along the Cumberland river belong to the horizon of the Madison bed. At any rate, the Fowler limestone itself is of Richmond Group age and the Richmond group is present at the crest of the anticline where it is cut by the Cumberland river.

If the interpretation of the rocks above given is correct, it will be seen that the term Cumberland sandstone includes a much larger series of rocks than the name Madison bed. The clayey rocks, with larger specimens of *Platystrophia lynx*, may even belong to the Lorraine.

EVIDENCE OF RICHMOND GROUP ON AGE OF CINCINNATI ANTICLINE

So far as present observations indicate, the Richmond group thins rapidly southward, but it remains to be proved that it is thinner along

the crest of the anticline southward than on both flanks, or that this thinning had any connection with the development of the present fold.

Lists of Fossils

CLINTON FOSSILS WEST OF THE CINCINNATI ANTICLINE, IN INDIANA, KENTUCKY AND TENNESSEE

In the following list the figures refer to the localities at which the fossils were found. No attempt has been made at any locality to get a complete list of all fossils present. Many specimens were found which are not given in this list. Only those specimens of which a record was retained are here included.

The numbers for the Indiana localities are the same as those used on the maps accompanying the Twenty-first and Twenty-second Reports of the Indiana Survey. Since these reports may still be obtained, no further description of these localities is necessary.

The numbers for the Tennessee localities are the same as those used on the map accompanying this paper.

The numbers used for the Kentucky localities need fuller identification.

1. Four miles northeast of La Grange, along the railroad to Pendleton, beyond the bridge across the railroad leading to Mrs Whalen's house.
5. Two miles east of Pewee valley, beyond Floydsburg, on the road to Todds point, before reaching Rodmans fork, in an open field south of the road, on the Alexander Sinclair farm.
22. On the new road from Middletown to Tucker station, a short distance north of entrance to the old Blankerbaker homestead.
26. At the Cedar Spring church, on the road from Jeffersontown to Seatonville.
29. Near Hays spring, on the pike from Louisville to Bardstown, a short distance north of the crossing over Floyds fork.
31. At the southwest corner of Mount Washington, along the Bardstown pike.
32. About a mile beyond Greenwells ford, on the hill road to Lick Skillet, about 200 feet south of the home of Mr Asa Lutes.
33. About a mile farther south, along the stream leading from the home of W. R. Greenwell eastward toward that of Jess Ruby.
39. Along the Nelson County line creek, a short distance below the home of James Roney.
48. On the east side of Bardstown, in the bed of the creek.
61. West of Cedar creek, along road crossing Cedar creek half a mile above junction with Beech fork, 5 miles southwest from Bardstown.
63. At crossing of small stream about 1.5 miles southwest from last locality.
71. Six miles east of Bardstown, along the railroad beyond Gasburg.

States	Indiana.							Kentucky.						Tennessee.							
Counties	Wayne.	Fayette.	Franklin.	Decatur.	Ripley.	Jefferson.	Clark.	Oldham.	Jefferson.	Bullitt.	Nelson.	Washington.	Marion.	Macon.	Sumner.	Davidson.	Cheatham.	Williamson.	Maury.	Hickman.	Lewis.
Proetus determinatus					84	57															
					123																
Illaenus daytonensis	E		220	188	87	23					48					12			8	29	33
					90	H														30	
					105	57															
					107	59															
						67															
Illaenus ambiguus	E		215		84	23		1			48		114		4	7	10		18		
					105	H					88										
					123	42															
						57															
						67															
Illaenus madisonianus					107	57	5														
Calymene vogdesi			220			H															
Calymene niagarensis						23							114								33
						57															
Lichas breviceps						23															
						57															
						H															
Phacops trisulcatus							5						114								
Dalmanites werthneri	E					23					48										
Encrinurus punctatus						H															
Orthoceras youngi						H															
Orthoceras rectum var. *junius*						H															
Orthoceras ignotum					90	H															
Orthoceras hanoverense						H															
Orthoceras virgulatum					110																
Bellerophon fiscello-striatus						23															
						H															
						57															
Bellerophon exiguus						H															
Bellerophon opertus						H															
Crytolites youngi						H															
Cyclonema bilix					117	23	8											16			
						H															
var. *varicosum*															4						
Platyostoma niagarense						57					88					6					
Pterinea brisa						57						100									

Orthis flabellites	E M	246	213 215 220 223 231		106 107 112 117 123 130 137	23 28 30 H 35 37 52 57 67	1 5 7 16	5	22 29	31 32 33 39	48 71 88 89	99 100 101
Platystrophia biforata	E M		215		107	23 30 H 52 57	1 5 7		26	33	48 61 71 88	100
Dalmanella elegantula	E		231		84 107 123	H 54 57	5		29		48 61 71 88 89 91	100
Orthis tenuis				188	84 107 123 87	H 57 59			22 29	31 30	48	
Triplecia ortoni											71	
Leptæna rhomboidalis		246	220	188	84 107 123	23 57 59	5	5			71 74 88	
Strophonella striata											74	
Strophonella patenta	E M				107 137	23 H 52 57 59 67	5					100
Strophonella hanoverensis			215 220		84 107 112 123	23 30 H 38 52 57 67	1				88	
Plectambonites transversalis var. *elegantula.*			220		84 105 107 123	23 30 H 36 37 54 57 59	1 5		22 29		48 88	
Stricklandinia triplesiana											48	

States	Indiana.							Kentucky.						Tennessee.							
Counties	Wayne.	Fayette.	Franklin.	Decatur.	Ripley.	Jefferson.	Clark.	Oldham.	Jefferson.	Bullitt.	Nelson.	Washington.	Marion.	Macon.	Sumner.	Davidson.	Cheatham.	Williamson.	Maury.	Hickman.	Lewis.
Stricklandinia triplesiana											89					G			19		
																14					
Camarotœchia neglecta						59	1				89				4						
Camarotœchia acinus var. *convexa.*						H															
Atrypa marginalis		246				23									4				19		
						38													8		
var. *mutistriata*			220			H		5													
var. *lataecorrugata*					123																
Aspidopora parmula					84	57															
Lioclemella ohioensis						23															
Phylloporina angulata		246	220																		
Hemitrypa ulrichi			220			23															
Ptilodictya whitfieldi						57															
Clathropora frondosa			220	201	107	23	5														
			228		112	H															
					117	57															
					123	59															
					146	67															
Phænopora ensiformis						23															
						30															
Phænopora expansa					117	23															
						36															
Phænopora fimbriata					84	23	1														
					107	57	5														
					110	67															
					126																
Phænopora multifida						H															
Pachydictya bifurcata			215		107	23	1														
			231		117	36	5		26												
						37															
Pachydictya crassa		246	220								48		113							25	
Pachydictya obesa			231			36															
Pachydictya turgida			231		107	23	1														
						36	5														
						42															
Rhinopora verrucosa	M	246	212		84	23	5		22	31			113			6			18		
			215		106	28			29										8		
			220		107	30															

74. Half a mile southwest of Balltown, on the road from Bardstown to New Haven.
88. Along the road half a mile north of New Hope.
89. About a mile east of New Hope, along the railroad west of crossing of Pottinger creek.
91. About 200 yards west of Coon hollow, less than a mile east of last locality (89).
99. Five miles west of Springfield, on hill road to Manton, near McIntire's store.
100. Half a mile east of McIntire's store, west of Wheatlys branch.
101. East of Wheatlys branch, at synclinal fold.
110. A quarter of a mile west of Loretto, south of the railroad.
113. About a mile southeast of Chicago, on road to Saint Marys.
114. Two miles south of Chicago, on road to Raywick, east of house of W. D. Miles.
116. East of the road, before steep descent of hill, less than a mile southward of the W. D. Miles locality.

The fauna of the Osgood and Laurel horizons is at present still under investigation.

WALDRON FOSSILS WEST OF THE CINCINNATI ANTICLINE IN TENNESSEE

All of the fossils in the following list are found in a single exposure at Newsom station, Tennessee. When recorded also from other localities, the numbers of these localities follow the name of the fossil. In this list all the less common species of brachiopods were submitted to Mr Charles Schuchert. The crinoids were submitted to Mr Frank Springer.

Lichas boltoni, var. *occidentalis*.
Dalmanites bicornis, only the margin of head known, as at Waldron, Indiana.
Dalmanites verrucosus, 4, 7, 10.
Ceraurus niagarensis, 7, 10.
Illænus armatus ?, only pygidia and one glabella of type figured in Waldron report.
Illænus, 1 species.
Acidaspis fimbriata ?, only free cheek.
Cyphaspis christyi.
Calymene niagarensis, 7, 10.
Hyolithes, 1 species.
Cornulites, 1 species, only young individuals apparently.
Spirorbis inornatus.
Orthoceras amycus, 7.
Strophostylus cyclostomus.
Platyostoma niagarense, 10.
Anastrophia internascens.
Plectambonites transversalis ?, very small individuals.
Strophonella semifasciata, 7.
Strophonella striata.
Stropheodonta, 1 species; belongs to subgenus *Brachyprion*, near *Str. profunda*, G.
Leptæna rhomboidalis, 7, 10.
Mimulus waldronensis.
Orthothetes subplanus, 7; also double convex form at 4, 10, 12.
Orthostrophia, 1 species; nearest related to *O. halli*, but with finer plications.
Rhipidomella hybrida; also a form, apparently mature, but of half the ordinary size, and slightly more convex.
Dalmanella elegantula, 7; also a variety with more prominent beak.

Cypricardinia arata.
Pterinia brisa, 7, 10.
Pterinia, 4 species, 7.
Amphicœlia leidyi, like Waldron form.
Eichwaldia reticulata, 7.
Meristina maria, 6, 7, 10.
Homœospira evax, 7.
Homœospira, 1 species, more convex than *H. sobrina*. Compare description of *Rhynchospira helena*, not the figures.
Whitfieldella nitida, G., 7.
Nucleospira pisiformis.
Cyrtia myrtea.
Spirifer crispus, variety simplex, 10; probably young of *crispus.*
Spirifer crispus.
Spirifer oligoptychus, 5, 7, 10; same as *Sp. eudora.*
Spirifer plicatellus.
Spirifer radiatus, 7.
Atrypa reticularis, 4, 5, G., 7, 10.
Atrypina disparilis.
Uncinulus stricklandi, 7, 10; *Rhynchonella tennesseensis* is only a slight variation from this form.
Camarotœchia indianensis.
Camarotœchia whitei.
Camarotœchia acinus, 7.
Rhynchotreta cuneata, var. *americana.*
Gypidula, 1 species; plications even less than in *G. rœmeri.*
Bilobites biloba, 7.
Crania siluriana.
Pholidops ovalis; apparently identical with *Ph. squamiformis.*
Lingula gibbosa.
Periechocrinus christyi (*Saccocrinus*).
Macrostylocrinus striatus; also var. *granulosus.*
Mariacrinus carleyi (*Glyptocrinus*).
Thysanocrinus inornatus (*Glyptaster*).
Lecanocrinus pusillus.
Melanocrinus æqualis.
Lyriocrinus melissa.
Eucalyptocrinus crassus.
Eucalyptocrinus magnus; also forms inter mediate between *magnus* and *crassus.*
Eucalyptocrinus elrodi; also a form apparently distinct.
Eucalyptocrinus tuberculatus ?
Eucalyptocrinus ovalis.
Stephanocrinus gemmiformis.
Stribalocystis gorbyi (*Caryocrinus*).
Drymotrypa niagarensis.
Diamesopora osculum.
Callopora elegantula.
Fistulipora neglecta.
Ceramopora ? confluens.
Favosites forbesi, var. *occidentalis*, G.
Favosites spinigerus.
Streptelasma radicans.
Streptelasma borealis (*Duncanella*).
Astylospongia præmorsa.

LOUISVILLE LIMESTONE FOSSILS AT PEGRAM AND BLEDSOE, TENNESSEE

Encrinurus punctatus ?, 9.
Calymene niagarensis, 9.
Meristina maria, 9.
Reticularia, 1 species, 9.
Spirifer foggi, 9.
Spirifer radiata, 9.
Atrypa reticularis, 9; both with fine and with coarse striations.
Wilsonia saffordi, 9.
Uncinulus tennesseensis, 9.
Conchidium nysius, 3.
Conchidium knappi, 3.
Pentamerus oblongus, 3.
Orthothetes subplanus, 9.
Lyellia discoidea, 9.
Lyellia puella, 9.
Heliolites subtubulatus, 9.
Heliolites interstinctus, 9.
Thecia minor, 9.
Thecia major, 9.
Halysites catenulatus, 3, 9.
Favosites forbesi, var. *discoidea*, 9.
Favosites favosus, 9.
Cœnites verticillata, 3.
Cladopora, 3 species, 9.
Cladopora reticulata, 3.
Alveolites, 1 species, 9; between *Niagarensis* and *verticillata.*

Rhipidomella hybrida, 3.
Platystrophia biforata. 3.
Fistulipora hemispherica, 9.
Pachydictya crassa, 9.
Calceola tennesseensis, 9; *operculum* only.
Lyellia americana, 3.
Alveolites louisvillensis, 9.
Cystiphyllum, 1 species, 9; much larger than *C. niagarense*.
Amplexus shumardi, 9.
Aulopora rœmeri (*repens*, of Rœmer), 9.

The brachiopods of this list were submitted to Mr Charles Schuchert.

DEVONIAN FOSSILS FOUND IN THE PEGRAM LIMESTONE IN TENNESSEE

**Nucleospira concinna*, 12.
Spirifer pennatus, 9,
Tropidoleptus carinatus, 9.
Camarotœchia carolina, var., 9.
**Stropheodonta demissa*, 12; interiors of brachial valves. Also a young specimen of a form known as the young of *Str. demissa* in New York, but considered a distinct form (*Str. erratica*) in Michigan.
**Stropheodonta perplana*, 12; exterior of pedicle valve.
**Rhipidomella penelope*, 9, 12; size of specimens too large for *vanuxemi*; specimens are interiors of pedicle valves.
Lingula, similar in outline and size to *L. cuyahoga* of Hall and Clarke.
Polypora levinodata, 9, 12.
Coscinium cribriforme, 12.
Unitrypa tegulata, 9, 12.
Nucleocrinus verneuili, 9.

The brachiopods marked with an asterisk were submitted to Mr Charles Schuchert.

The bryozoans were examined by Mr E. O. Ulrich.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 12, PP. 445-538, PLS. 42-45 NOVEMBER 27, 1901

PROCEEDINGS OF THE THIRTEENTH ANNUAL MEETING, HELD AT ALBANY, NEW YORK, DECEMBER 27, 28, AND 29, 1900, INCLUDING PROCEEDINGS OF THE SECOND ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT SAN FRANCISCO, DECEMBER 28 AND 29, 1900

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

Session of Thursday, December 27

The Society was called to order by the President, Dr George M. Dawson, in the chapel of the Albany (Boys) Academy. All the sessions of the meeting were held in this place and the President presided at all the sessions except one.

Dr F. J. H. Merrill, State Geologist, spoke a few words of welcome to the Society, and announced that the formal address of welcome, expected at this time, by the Honorable T. Guilford Smith, Chairman of the State Museum Committee, would be given at the dinner in the evening. Dr John M. Clarke, State Paleontologist, also welcomed the Society in a brief address.

Doctor Clarke read the following invitation from the Director of the State Library:

State Library, Albany, New York, *December 27, 1900.*

John M. Clarke, Ph. D., *Albany, New York.*

Dear Doctor Clarke: Will you kindly extend to the visiting geologists a most cordial invitation to visit the State Library and Home Education departments, where we should be more than delighted to show them anything of our peculiar work in which they are interested? We appreciate the honor done to our old city

by this gathering of the most distinguished geologists of the country, and should esteem it a privilege to show them any courtesy in the power of our departments.

Yours very truly,

MELVIL DEWEY, *Director*.

The Report of the Council was called for and was presented, in print, by the Secretary, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Thirteenth Annual Meeting Assembled:

The Council congratulates the Society upon its continued prosperity, as shown in the reports of the officers. The affairs of the Society are in excellent condition, and the Council has no recommendations or special business to present. During the past year the Council has held its stated meetings in connection with the meetings of the Society, the attendance at the Summer Meeting in New York being one less than a quorum.

SECRETARY'S REPORT

To the Council of the Geological Society of America:

Meetings.—The records of the Twelfth Annual Meeting, held in Washington, December, 1899, and the Twelfth Summer Meeting, in New York, June, 1900, are in print and will soon be distributed, probably before this report is read. According to the custom, the Summer Meeting occupied one day of the time of Section E, American Association for the Advancement of Science.

Membership.—During the year one Fellow has died, Mr Franklin Platt. The eight candidates elected at the Washington Meeting all qualified. Two names have been erased for non-payment of dues, which leaves on the last printed list (June, 1900, Bull., vol. 11, p. 629) 245 names. To this must be added the three names of the men elected at the Summer Meeting, making the present enrollment 248. Five Fellows are delinquent for two years. Eight nominations are before the Council. As only one candidate had been fully approved by the Council, the Secretary thought it better to issue no nomination and ballot for the Albany Meeting.

Form of reports.—For several years the Secretary's reports of Bulletin distribution and sales have been presented in detailed tabulation, including complete statistics for the published volumes. The number of published volumes is now so large that such tables are complicated and expensive to print, and will be discontinued. Instead of these the statistics will be given for the fiscal year, with a few grand totals. The

Secretary's books show all transactions. At the end of the second decade a full tabulation and comparison should be made.

Distribution of Bulletin.—Since November 30, 1899, the completed copies of volume 10 have been distributed. The 85 copies sent to exchanges, 73 sold to libraries, 3 bound for use of officers and library, and 1 donated, appear in the printed report for last year (Bull., vol. 11, p. 513); also three brochures distributed. In addition to those published figures (for volume 10), five volumes have been sold to libraries and two sold to Fellows; ten brochures have been sent to supply deficiencies and six have been sold to the public. Of the preceding nine volumes, 26 copies have been sold to libraries during the year and 13 copies to Fellows. Eleven brochures have been donated to supply deficiencies or losses in the mails, and ten have been sold to the public.

Of volume 11, seven brochures have been sent to fill deficiencies and twenty-three have been sold to the public. Most of these sales were of Mr Weed's paper on "Enrichment of Mineral Veins;" to supply this demand the Secretary purchased an extra supply from the author.

Subscriptions.—Since it has become largely the practice for libraries to order their periodicals through news agents, it is difficult to determine the number of institutions which might be regarded as regular subscribers to the Bulletin. Seventy-eight copies of volume 10 have been sold to the public.

Bulletin sales.—The following table shows the income for the year from sale of the Bulletin:

RECEIPTS FROM SALE OF BULLETIN, DECEMBER 1, 1899, TO DECEMBER 1, 1900

	Complete volumes.			Brochures.		Grand total.
	Libraries.	Fellows.	Total.	Libraries.	Fellows.	
Volume 1	$15 00	$9 00	$24 00	$3 75	....	$27 75
Volume 2	15 00	9 00	24 00	....	....	24 00
Volume 3	15 00	4 00	19 00	....	....	19 00
Volume 4	15 00	3 50	18 50	20	....	18 70
Volume 5	15 00	4 00	19 00	40	....	19 40
Volume 6	10 00	4 00	14 00	50	....	14 50
Volume 7	10 00	4 00	14 00	75	....	14 75
Volume 8	10 00	4 00	14 00	....	....	14 00
Volume 9	25 00	4 00	29 00	....	....	29 00
Volume 10	255 00	8 00	263 00	3 40	....	266 40
Volume 11	90 00	....	90 00	5 00	....	95 00
Volume 12	15 00	....	15 00	....	....	15 00
	$490 00	$53 50	$543 50	$14 00	....	$557 50

Receipts for the fiscal year	$557 50
Previous receipts, to November 30, 1899	4,682 51
Total receipts to date	$5,240 01
Charged and uncollected	55 55
Total Bulletin sales to date	$5,295 56

Of the amount uncollected perhaps $11 will have to be charged to profit and loss.

Exchanges.—No addition has been made to the list of institutions receiving the Bulletin as donation during the past three years, but your Special Committee on Exchanges will recommend a few additions even if it requires the omission of some now listed.

Expenses.—The following table shows the cost of administration from the Secretary's office for the past year:

EXPENDITURE OF SECRETARY'S OFFICE FOR THE FISCAL YEAR, NOVEMBER 30, 1899, TO NOVEMBER 30, 1900

Account of Administration

Postage	$14 73	
Expressage	3 66	
Printing (including stationery and records)	51 55	
Meetings (not included in printing)	51 85	
Binding	4 00	
Total		$125 79

Account of Bulletin

Postage	$137 74	
Expressage and freight	66 83	
Wrapping material and labels	33 91	
Purchase of brochures	6 40	
Collection of checks	3 95	
Total		$248 83
Total expenditure for year		$374 62

Respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, N. Y., *December 20, 1900.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer submits herewith his annual statement of the receipts and disbursements for the year ending December 1, 1900, with other statistics to date.

Statement of Receipts and Expenditures.

RECEIPTS.

Balance in the treasury November 30, 1899				$3,030 02
Fellowship fees 1898 (5)	$50 00			
" " 1899 (24)	240 00			
" " 1900 (149)	1,490 00			
		$1,780 00		
Initiation fees (12)		120 00		
Life commutation fees (5)		500 00		
Interest on investments:				
Tioga Township, Kansas, bonds	$70 00			
Cosmos Club bonds	85 00			
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00			
Texas Pacific Railroad bonds	100 00			
On deposits in Security Trust Co.	97 23			
		370 23		
Sales of publications		557 50		
			3,327 73	
Total amount of receipts				$6,357 75

Total amount of receipts brought forward				$6,357 75

EXPENDITURES.

Administration, library, and distribution of Bulletin—				
Secretary's office:				
Administration	$87 69			
Distribution of Bulletin	195 30			
Allowance (for ordinary expenses)	500 00			
		$782 99		
Treasurer's office		21 65		
Librarian's office		11 85		
			$816 49	
Publication of Bulletin:				
Printing		$1,865 75		
Engraving		548 06		
Editorial expenses (including allowance for personal and office expenses)		250 00		
			2,663 81	
Total amount of expenditures				$3,480 30
Balance in treasury November 30, 1900				$2,877 45

Two Fellows were dropped from the roll during the year for non-payment of dues; five (5) others are delinquent for two years, and after January 1 will be subject to loss of Fellowship for non-payment, while thirty-five (35), a much larger number than usual, are delinquent for one year—1900.

Five Fellows, namely, A. H. Brooks, J. B. Hastings, A. F. Foerste, Samuel L. Penfield, and Heinrich Ries, have commuted for life since the last report, thus raising the number of Life Members to forty-eight (48).

No permanent investments have been made during the year, but a large deposit has been kept with the Security Trust Company of Rochester, New York, on which the Society is still paid interest on monthly balances at the rate of four (4) per cent. The item of $97.23 interest shows the income from this source, which, added to the $273.00 from the invested fund of $5,000, makes the total income of $370.23 from the Society's surplus funds.

The detailed financial transactions of the Society are presented in the statement on the preceding page.

Respectfully submitted.

I. C. WHITE,

MORGANTOWN, WEST VA., *December 20, 1900.* *Treasurer.*

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor takes pleasure in announcing that the past year has been a very satisfactory one in the matter of the Society's publications. The last brochure of volume 11, the most copiously illustrated volume ever issued by the Society and next to the largest in number of pages, was completed October 31. It consists of 651 pages of text and xii pages of preliminary matter and is illustrated with 58 plates and 37 cuts. Such of the papers of the Summer meeting as have been offered for publication are in print, and make 56 pages of volume 12. If the papers of the Winter meeting are promptly handed in by the authors, there is no reason why this volume should not be completed by June, thus avoiding the delay which sometimes arises from the scattering of members to their various fields of summer work, and their consequent inaccessibility for the correction of proof.

At this writing the index of volumes 1 to 10, inclusive, is in type. Involving as it did somewhat more work than was first anticipated, it was not practicable to issue it during the summer, but it will be disposed of before the close of the year.

Although exact classification is not attempted, the following compara-

tive table presents reasonably good analyses of the contents of volumes 7, 8, 9, 10, and 11:

Divisions.	*Vol. 7. Pages.*	*Vol. 8. Pages.*	*Vol. 9. Pages.*	*Vol. 10. Pages.*	*Vol. 11 Pages.*
Areal geology	38	34	2	35	65
Dynamic geology	3	24	85	24	110
Economic geology	4	14	16	28	7
Glacial geology	105	98	138	96	21
Historical	..	..	..	16	46
Memoirs of deceased members	28	8	12	27	60
Official matter	56	69	54	72	59
Paleontology	123	58	64	68	188
Petrology	40	43	44	59	54
Physiographic geology	53	5	..	37	10
Relation of geology to pedagogy	12	..	..	..	..
Rock decomposition	74	26	17	9	..
Stratigraphic geology	21	67	28	62	31
Terminology	1	..	..	1	..
Total	558	446	460	534	651

The average cost of the ten volumes is given below, and with it will be compared the cost of each volume as it appears annually:

	Average. Vols. 1–10.	Vol. 11.
	pp. 544. pls. 26.	pp. 651. pls 58.
Letter-press	$1,465 14	$1,815 56
Illustrations	290 40	373 68
	$1,755 54	$2,189 24
Average per page	$3 23	$3 30

From the foregoing it will be seen that, when the unusual illustration of volume 11 is taken into account, there has been no tendency to carelessness in the matter of cost of publication, but, on the contrary, the conservative policy first adopted has been maintained.

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

WASHINGTON, D. C., *December 17, 1900.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The list of additions to the library between March, 1899, and June, 1900, will be found in print in the Bulletin, volume 11, pages 617–628.

Some effort has been made to complete imperfect volumes of exchanges and to effect exchange in a few cases in which the Society's Bulletin

was being sent but no exchange received. For cordial response to such effort the Society is indebted to the Geological Survey of Great Britain, Geological Survey of Canada, Royal Society of Canada, New York Academy of Sciences, Societa Geologica Italiana, Société Belge de Géologie, K. Sachische Gesellschaft der Wissenschaften, Comité Géologique de la Russie, and Magyarhoni Foldtani Tarsulat.

One hundred and eighty volumes have been bound during the past year, and the arrearage in binding mentioned in the Librarian's report of two years ago will be finally wiped out during the coming year.

The expenses of this office during the past eighteen months are as follows:

Express	$3 45
Postage	1 15
Postal cards	6 00
Printing of same	1 25
Total	$11 85

Respectfully submitted.

H. P. Cushing,
Librarian.

Cleveland, Ohio, *December 1, 1900.*

On motion of the Secretary, it was voted to defer consideration of the Council report until the following day.

As the Auditing Committee, to examine the accounts of the Treasurer, the Society elected E. O. Hovey and H. P. Cushing.

ELECTION OF OFFICERS

The result of the balloting for officers for 1901, as canvassed by the Council, was announced by the President, and the officers were declared elected as follows:

President:

Charles D. Walcott, Washington, D. C.

First Vice-President:

N. H. Winchell, Minneapolis, Minn.

Second Vice-President:

S. F. Emmons, Washington, D. C.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Editor:

J. Stanley-Brown, Washington, D. C.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councillors:

Samuel Calvin, Iowa City, Iowa.
A. P. Coleman, Toronto, Can.

In the absence of the author, the following memoir was read by W. M. Davis:

MEMOIR OF FRANKLIN PLATT

BY PERSIFOR FRAZER

The subject of this sketch was descended from an old English family, of which one branch had settled in New Jersey. His father was Franklin Platt and his mother was Clara A. Greenough, of Sunbury, Pennsylvania. He was born November 19, 1844, in Philadelphia, and died at Cape May, New Jersey, July 24, 1900.

In 1860 he entered the sophomore class in the University of Pennsylvania, but left at the end of the college year. His ~~older~~ younger brother, ~~Ebenezer~~ William G. Platt, was a student with him, and was later associated with him in geological work.

In 1863 Mr Platt served as a private, from June 26 to August 1, in Company D of the old militia regiment of Philadelphia, known as the "Gray Reserves," during the emergency campaign, when Lee invaded Pennsylvania.

In 1864 he was appointed an aid on the United States Coast and Geodetic Survey. He was without commission, in a party of topographers, under Mr Dorr, which, under command of General O. M. Poe, accompanied Sherman's army in the famous "march to the sea."

After the civil war Platt read geology in the office of Mr Benjamin S. Lyman. In 1870 he became associated with the writer for one year as reporting geologist.

When the Second Geological Survey of Pennsylvania was organized Mr Platt was chosen as an assistant and assigned to the Clearfield and Jefferson Counties district in the bituminous coal field. When the survey terminated he opened an office with his brother, W. G. Platt, as consulting geologist, especially on coal. In 1881 they located lands for the Rochester and Pittsburg Coal and Iron Company, and later he became its consulting engineer, and finally its president for several years.

Mr Platt retired from active work about 1891. In later years he was an invalid and spent his evenings in his apartment, 1820 Chestnut street, Philadelphia. His serious illness began in 1898, when his vision failed so that he could not read. He died suddenly at Cape May, and is buried in Woodlands cemetery, Philadelphia. He was never married.

Franklin Platt was a superior man intellectually. He had a phenomenal memory, strong prejudices, and was not easily persuadable. He shunned the society of ladies and emotional influences. He was discreet, politic, and calm in judgment, with great power of estimating the relative value of things. In person he was tall and spare, with usually a slight stoop, and of fair complexion.

Mr Platt was a member of several scientific societies, and an original Fellow of the Geological Society. Though a member of the Philadelphia Academy of Natural Sciences from 1868 to 1900, he never contributed to its proceedings. Following is the list of his geological writings:

BIBLIOGRAPHY

Character of some Sullivan County coals. (Read February 7, 1879.) *Proc. Amer. Phil. Soc.*

Reports of the Second Geological Survey of Pennsylvania:

- H. First report on Clearfield and Jefferson counties. 1875.
- H 2. Report on Cambria and Somerset counties (in collaboration with W. G. Platt). 1877.
- H 3. Report on Somerset county (with W. G. Platt). 1877.
- L. Report on the Youghiogheny coke manufacture (with J. B. Pearse), with other reports. 1876.
- G 3. Report on the coal fields of Potter county. 1880.
- G 4. Notes on the Tangascootac coal basin. 1880.
- A 2. Report on the causes, kinds, and amounts of waste in mining anthracite. 1881.
- T. Blair county, with atlas. 1881.
- Sundry special reports in the Annual Report of 1885.

The presentation of scientific communications was declared in order, and the President called for the first paper of the printed program, as follows;

EXPERIMENTAL WORK ON THE FLOW OF ROCKS[*]

BY FRANK D. ADAMS

[*Abstract.*]

That rocks, under the conditions to which they are subjected in certain parts of the earth's crust, become bent and twisted in the most complicated manner is a

[*] This paper is published *in extenso* in the Philosophical Transactions of the Royal Society of London, series A, vol. 195, pp. 363–401, plates 22–25.

fact which was recognized by the earliest geologists, and it needs but a glance at any of the accurate sections of contorted regions of the earth's crust which have been prepared in more recent years to show that there is often a transfer or "flow" of material from one place to another in the folds. The manner in which this contortion, with its concomitant "flowing," has taken place is, however, a matter concerning which there has been much discussion, and a wide divergence of opinion. Some authorities have considered it to be a purely mechanical process, while others have looked upon solution and redeposition as playing a necessary rôle in all such movements. The problem is one on which it would appear that much light might be thrown by experimental investigation. If movements can be induced in rocks under known conditions, with the reproduction of the structures found in deformed rocks in nature, much might be learned concerning not only the character of the movements, but also concerning the conditions which are necessary in order that the movements in question may take place.

It is generally agreed that three chief factors contribute to bringing about the conditions to which rocks are subjected in the deeper parts of the earth's crust, where folding with concomitant flowing is most marked. These are:

1. Great pressure.
2. High temperature.
3. Percolating waters.

With regard to the first factor, it must be noted that mere cubic compression does not produce movements of the nature of flowing, although it may produce molecular rearrangement in the rock. A differential pressure is necessary to give movement to the mass. As Heim has pointed out, there is reason to believe that "Umformung ohne Bruch" takes place when a rock is subjected to a pressure which, while greater in some directions than in others, in every direction exceeds the elastic limit of the rock in question. Whether all these factors, or only certain of them, are actually necessary for the production of rock deformation is a question which also requires to be determined by experiment, for by experiment the action of each can be studied separately, as well as in combination with the others.

In the present paper a first contribution to such a study is presented, pure Carrara marble being the rock selected for study. The investigation is now being extended to dolomites, granites, and other rocks.

In order to submit the marble to a differential pressure, under the conditions above outlined, it was sought to inclose the rock in some metal having a higher elastic limit than marble and at the same time possessing considerable ductility. After a long series of experiments heavy wrought-iron tubes of special construction were adopted. These were made, following the plan adopted in the construction of ordnance, by rolling thin strips of Low Moor iron around a bar of soft iron and welding the strips successively to the bar as they were rolled around it. The core of soft iron composing the bar was then bored out, leaving a tube of Low Moor iron, the sides being about one-fourth of an inch in thickness, and so constructed that the fibers of the iron ran around the tube instead of being parallel to its length. These were found to answer the requirements admirably.

The following procedure was then adopted: Columns of the marble, an inch or in some cases 0·8 inch in diameter and about 1·5 inch in length, were accurately turned and polished. The tube was then very accurately fitted around the marble. This was accomplished by giving a very slight taper to both the column and the

FIGURE 1.—IRON TUBE INCLOSING MARBLE BEFORE AND AFTER DEFORMATION OF LATTER

FIGURE 2.—MARBLE COLUMN OF ORIGINAL DIMENSIONS AND SAME COLUMN AFTER DEFORMATION

DEFORMATION OF MARBLE

interior of the tube, and so arranging it that the marble would only pass half way into the tube when cold. The tube was then expanded by heating, so as to allow the marble to pass completely into it and leave about 1·25 inch of the tube free at either end. On allowing the tube to cool a perfect contact between the iron and the marble was obtained. In some experiments the tube was subsequently turned down, so as to be somewhat thinner immediately around the marble. Into either end of the tube containing the column an accurately fitting steel plug or piston was then inserted, and by means of these the pressure was applied. The high pressure required was obtained by means of a powerful press especially constructed for the purpose, consisting of a double hydraulic "intensifier," the water pressure being in the first instance obtained from the city mains. By means of this machine pressures up to 13,000 atmospheres could be exerted on the columns having a diameter of 0·8 inch, and the pressures could be readily regulated and maintained at a constant value for months at a time if required.

It having been ascertained that the columns of the marble 1 inch in diameter and 1½ inch in height crushed at a pressure of from 11,430 to 12,026 pounds to the square inch, the column inclosed in its wrought-iron tube, in the manner above described, was placed in the machine and the pressure applied gradually, the exterior diameter of the tube being accurately measured at frequent intervals. No effect was noticeable until a pressure upon the marble, varying of course with the thickness of the inclosing tube, but generally about 18,000 pounds to the square inch, was reached, when the tube was found to slowly bulge, the bulge being symmetrical and confined to that portion of the tube surrounding the marble. The distension was allowed to increase until the tube showed signs of rupture, when the pressure was removed and the experiment concluded. The conditions under which the marble was submitted to pressure were four in number:

1. At the ordinary temperature in the absence of moisture (cold dry crush).
2. At 300 degrees centigrade in the absence of moisture (hot dry crush).
3. At 400 degrees centigrade in the absence of moisture (hot dry crush).
4. At 300 degrees centigrade in the presence of moisture (hot wet crush).

Eight experiments were made on marble columns at the ordinary temperature in the absence of moisture, the rate at which the pressure was applied differing in different cases, and the consequent deformation being in some cases very slow and in others more rapid, the time occupied by the experiment being from 10 minutes to 64 days. In plate 42, figure 1, is seen, on the left, the iron tube inclosing the marble and ready to be placed in the machine; on the right, the same tube after the marble had been slowly deformed during a period of 64 days. The amount of deformation was not in all cases equal, as some of the tubes showed signs of rupture sooner than others. On the completion of the experiment the tube was slit through longitudinally by means of a narrow cutter in a milling machine along two lines opposite one another. The marble within was found to be still firm and compact, and to hold the respective sides of the tube, now completely severed from one another, so firmly together that it was impossible without mechanical aids to tear them apart. By means of a steel wedge driven in between them, however, they could be separated, but only at the cost of splitting the marble through longitudinally. In plate 42, figure 2, the deformed marble inclosed in the tube shown in figure 1 is seen freed from latter, and beside it is a marble column of the dimensions which it originally possessed (natural size). The half columns of the marble, now deformed, generally adhere so firmly to the tube that it

is necessary to spread the latter in a vise in order to set them free. The deformed marble, while firm and compact, differs in appearance from the original rock in possessing a dead white color, somewhat like chalk, the glistening cleavage surfaces of the calcite being no longer visible. The difference is well brought out in certain cases, owing to the fact that a certain portion of the original marble often remains unaltered and unaffected by the pressure. This when present has the form of two blunt cones of obtuse angle whose bases are the original ends of the columns resting against the faces of the steel plugs, while the apices extend into the mass of the deformed marble and point toward one another. These cones, or rather parabolas of rotation, are developed, as is well known, in all cases when cubes of rock, Portland cement, or cast iron are crushed in a testing machine in the ordinary manner. In the present experiments they seldom form any large portion of the whole mass.

In order to test the strength of the deformed rock, three of the half columns from different experiments, obtained as above described, were selected and tested in compression. The first of these, which had been deformed very slowly, the experiment extending over 64 days, crushed under a load of 5,350 pounds per square inch; the second, which had been deformed in 1½ hours, crushed under a load of 4,000 pounds per square inch; while the third, which had been quickly deformed, the experiment occupying only 10 minutes, crushed under a load of 2,776 pounds per square inch. As mentioned above, the original marble, in columns of the dimensions possessed by these before deformation, was found to have a crushing weight of between 11,430 and 12,026 pounds per square inch. These figures show that, making all due allowance for the difference in shape of the specimens tested, the marble after deformation, while in some cases still possessing considerable strength, is much weaker than the original rock. They also tend to show that when the deformation is carried on slowly the resulting rock is stronger than when the deformation is rapid.

Thin-sections of the deformed marble, passing vertically through the unaltered cone and the deformed portion of the rock, were readily made, and when examined under the microscope clearly showed the nature of the movement which had taken place. The deformed portion of the rock can be at once distinguished by its turbid appearance, differing in a marked manner from the clear transparent mosaic of the unaltered cone. This turbid appearance is most marked along a series of reticulating lines running through the sections, which when highly magnified are seen to consist of lines or bands of minute calcite granules. They are lines along which shearing has taken place. The calcite individuals along these lines have broken down, and the fragments so produced have moved over and past one another, and remain as a compact mass after the movement ceased. In this granulated material are inclosed great numbers of irregular fragments and shreds of calcite crystals, bent and twisted, which have been carried along in the moving mass of granulated calcite as the shearing progressed. This structure is therefore cataclastic, and is identical with that seen in the feldspars of many gneisses.

Between these lines of granulated material the marble shows movements of another sort. Most of the calcite individuals in these positions can be seen to have been squeezed against one another, and in many cases a distinct flattening of the grains has resulted, with marked strain shadows, indicating that they have been bent or twisted. They show, moreover, a finely fibrous structure in most cases, which, when highly magnified, is seen to be due to an extremely minute poly-

FIGURE 1. MICROPHOTOGRAPH OF CARRARA MARBLE BEFORE DEFORMATION. × 50 DIAMETERS

FIGURE 2. MICROPHOTOGRAPH OF CARRARA MARBLE AFTER HAVING BEEN SLOWLY DEFORMED AT 300° C. × 50 DIAMETERS

MICROPHOTOGRAPHS OF CARRARA MARBLE

synthetic twinning. The chalky aspect of the deformed rock is, in fact, due chiefly to the destruction by this repeated twinning of the continuity of the cleavage surfaces of the calcite individuals, thus making the reflecting surfaces smaller. By this twinning the calcite individuals are enabled under the pressure to alter their shape somewhat, while the flattening of the grains is evidently due to movements along the gliding planes of the crystals. In these parts, therefore, the rock presents a continuous mosaic of somewhat flattened grains.

From a study of the thin-sections it seems probable that very rapid deformation tends to increase the relative abundance of the granulated material, and in this way to make the rock weaker than when the deformation is slow.

When the marble is heated to 300 degrees centigrade in a suitably constructed apparatus and is then subjected to deformation under conditions which otherwise are the same as before, the cataclastic structure is found to be absent and the strength of the deformed marble rises to 10,652 pounds to the square inch—that is to say, it is nearly as strong as the original rock. The calcite grains, which in the original rock are practically equidimensional, are now distinctly flattened, some of them being three or even four times as long as they are wide. Some grains can be seen to have been bent around others adjacent to them, the twin lamellæ curving with the twisted grain. In others again of these twisted lamellæ the twinning only extends to a certain distance from the margin, leaving a clear untwinned portion in the center. The rock consists of a uniform mosaic of deformed and for the most part highly twinned calcite individuals.

Plate 43, figure 1, shows a microphotograph of a thin-section of the Carrara marble used in the experiments. The individual grains have very nearly the same diameter in every direction, although differing somewhat in size among themselves. Twinning is seen only in two or three grains, and in these is represented by a few broad lamellæ. The section was photographed in ordinary light and magnified 50 diameters.

Plate 43, figure 2, shows a microphotograph of the same rock after having been slowly deformed during 124 days at a temperature of 300 degrees centigrade. The individual grains can be seen to be distinctly flattened, giving a certain foliation to the rock, and also to possess the fibrous appearance referred to as resulting from polysynthetic twinning. It was photographed between crossed nicols and magnified 50 diameters.

When the deformation is carried out at 400 degrees centigrade, no trace of cataclastic structure is seen.

An experiment was then made in which the marble was deformed at 300 degrees centigrade, but in the presence of moisture, water being forced through the rock under a pressure of 460 pounds per square inch during the deformation, which extended over a period of fifty-four days, or nearly two months. Under these conditions the marble yielded in the same manner as when deformed at 300 degrees centigrade, in the absence of moisture, that is by movements on gliding planes and by twinning, but without cataclastic action. The deformed marble, however, when tested in compression, was found actually to be slightly stronger than a piece of the original marble of the same shape. The structure developed was identical with that of the marble deformed at 300 degrees centigrade in the absence of water. The presence of water, therefore, did not influence the character of the deformation. It is quite possible, however, that there may have been a deposition, of infinitesimal amount, of calcium carbonate along very minute cracks or fissures,

which thus helped to maintain the strength of the rock. No signs of such deposition, however, were visible.

By studying the marble deformed at a temperature of 300 degrees centigrade, or better at 400 degrees centigrade, it will be seen that structures induced in it by the movements, and the nature of the motion, are precisely the same as those observed in metals when they are deformed by impact or by compression. In a recent paper by Messrs Ewing and Rosenhain, "Experiments in Micro-metallurgy: Effects of Strain," which appeared in the Proceedings of the Royal Society of London, three photographs of the same surface of soft iron, showing the results of progressive deformation under pressure, are shown, which photographs could not be distinguished from those of thin-sections of the marble described in the present paper, at corresponding stages of deformation. In both cases the movements are caused by the constituent crystalline individuals sliding upon their gliding planes or by polysynthetic twinning. In both cases the motion is facilitated by the application of heat. The agreement between the two is so close that the term "flow" is just as correctly applied to the movement of the marble in compression under the conditions described as it is to the movement which takes place in gold when a button of that metal is squeezed flat in a vise, or in iron when a billet is passed between rolls.

In order to ascertain whether the structures exhibited by the deformed marble were those possessed by the limestones and marbles of contorted districts of the earth's crust, a series of forty-two specimens of limestones and marbles from such districts in various parts of the world were selected and carefully studied. Of these, sixteen were found to exhibit the structures seen in the artificially deformed marble. In these cases the movements had been identical with those developed in the Carrara marble. In six other cases the structures bore certain analogies to those in the deformed rock but were of doubtful origin, while in the remaining twenty the structure was different.

The following is a summary of the results arrived at:

1. By submitting limestone or marble to differential pressures exceeding the elastic limit of the rock and under the conditions described in this paper, permanent deformation can be produced.

2. This deformation, when carried out at ordinary temperatures, is due in part to a cataclastic structure and in part to twinning and gliding movements in the individual crystals comprising the rock.

3. Both of these structures are seen in contorted limestones and marbles in nature.

4. When the deformation is carried out at 300 degrees centigrade, or better at 400 degrees centigrade, the cataclastic structure is not developed, and the whole movement is due to changes in the shape of the component calcite crystals by twinning and gliding.

5. This latter movement is identical with that produced in metals by squeezing or hammering, a movement which in metals, as a general rule, as in marble, is facilitated by increase of temperature.

6. There is therefore a flow of marble just as there is a flow of metals, under suitable conditions of pressure.

7. The movement is also identical with that seen in glacial ice, although in the latter case the movement may not be entirely of this character.

8. In these experiments the presence of water was not observed to exert any influence.

9. It is believed, from the results of other experiments now being carried out but not yet completed, that similar movements can, to a certain extent at least, be induced in granite and other harder crystalline rocks.

In the discussion of Professor Adams' paper remarks were made by G. K. Gilbert, B. K. Emerson, J. E. Wolff, and C. D. Walcott, with replies by the author.

The Secretary made announcement of details concerning the customary dinner, which was to be at 7 o'clock in the evening, and also concerning the reception tendered the Society by Doctor Merrill on Friday evening.

The second paper read was

GEOMORPHOGENY OF THE KLAMATH MOUNTAINS

BY J. S. DILLER

[*Abstract*]

During the Neocene the Klamath Mountain region of northwestern California and southwestern Oregon by long continued erosion was reduced to a peneplain and the resulting marine sediments rich in fossils deposited along the ocean border recorded its age.

The Neocene strata were compressed and tilted, and with the Klamath peneplain and monadnocks uplifted somewhat differentially several hundred feet above its former level.

The invigorated streams in the rather long succeeding epoch of stability cut wide valleys across the peneplain to the coast, where extensive wave-cut terraces were developed.

A much greater differential uplift followed, to an altitude for the Klamath peneplain near the coast of 1,200 to 2,000 feet, and near the crest of the range 7,000 feet, causing the streams to cut deep canyons before the close of the glacial period.

Near the northern border of the Klamath mountains on the coast there has been a recent subsidence converting the lower courses of the rivers into tidal inlets.

Remarks on the paper were made by the President, M. R. Campbell, W. M. Davis, G. O. Smith, and G. K. Gilbert.

The next paper was read, in the absence of the author, by C. D. Walcott.

ORIGIN AND STRUCTURE OF THE BASIN RANGES

BY J. E. SPURR

This paper is printed as pages 216–270 of this volume.

The Society adjourned for luncheon. At 2.30 p m the Society reconvened, and the following paper was read:

TUFF CONE AT DIAMOND HEAD, HAWAIIAN ISLANDS

BY C. H. HITCHCOCK

[*Abstract*]

Since the publication of the paper on the Geology of Oahu,* the author has had an extensive correspondence with Doctor W. H. Dall and Doctor S. E. Bishop, of Honolulu, respecting the origin of this cone. The first thinks that coralline beds are interstratified with the tuff, implying several periods of eruption, between which the sea encroached on the land. The second insists that there was only one brief eruption of the tuff which produced the cone with coralline fragments included, after which eolian beds accumulated on the southern side. Both of those views were briefly stated. Doctor Bishop's paper, with an excellent topographic map of the cone, is printed in full in the American Geologist.†

The following paper was then read:

HYPOTHESIS TO ACCOUNT FOR THE EXTRA-GLACIAL ABANDONED VALLEYS OF THE OHIO BASIN

BY M. R. CAMPBELL

[*Abstract*]

The lower courses of the Allegheny, Monongahela, Kanawha, Guyandot, Big Sandy, and Kentucky rivers are characterized by abandoned channels, which generally range from 100 to 200 feet above the present streams. Generally these channels are deeply covered with silt, but sometimes the rock floor is only partially obscured by a thin layer of sand and gravel. The streams which have forsaken these valleys have sought new routes, along which they have carved deep channels through the upland topography. Teay valley, in West Virginia, is perhaps the most noted example, but the old channels at Carmichael and Masontown, on the Monongahela river, and opposite Parker, on the Allegheny river, are also well known.

No reason has been assigned for the abandonment of these channels; they can not be considered as "ox-bows," and they are all beyond the limit of glacial ice. The present hypothesis seeks to explain them through the breaking up of river ice and the formation of local ice-dams which were of sufficient height to force the water over the lowest divide in the rim of the basin and which persisted long enough for the stream to intrench itself in its new position.

The paper was discussed by I. C. White, W. M. Davis, G. K. Gilbert, and

---

* Bull. Geol. Soc. Am., vol. xi, pp. 15-60.

† Amer. Geologist, vol. xxvii, January, 1901, pp. 1-5.

A. P. Brigham. The following communication from E. H. Williams, Jr., was read by the Secretary as a part of the discussion:

THE ALLEGED PARKER CHANNEL

BY E. H. WILLIAMS, JR.

The Allegheny river from Irvineton to Red Bank, Pennsylvania, marks approximately the edge of the earliest glacier. The ice moving up the valleys of northwestern Pennsylvania went against drainage and produced slack water which has left its deposits throughout the western part of the state. The elevation of this water varies. About Warren it is above 1,600 feet above tide; about Franklin, above 1,400 feet above tide, and this level is carried to Foxburg, which is immediately above Parker and not far from the northern end of the vertically walled gorge, that replaces the valleys with sloping sides which obtain above Emlenton and below Monterey. Below the level of slack water we find the surface capped with a deposit varying from sand to clay locally, and from a few inches in thickness to many feet. It extends down to the present drainage levels, and is stratified parallel to the underlying contours, so that we can conclude that those contours were determined before the deposition. In this slack water were dropped, wherever shoulders of hills produced eddies, deposits varying from clean sand to accumulations of boulders. The line of the current is shown by thin deposits and by the bosses of hard rock polished by the sands and lying with slight covering.

The alleged abandoned channel near Parker has been noticed so frequently that it need not be described. It is sufficient to say that its highest part is about 250 feet above the rock floor of the Allegheny, and 190 feet above water level. The glacial water level was 500 feet higher, or over 300 feet above the highest part of this alleged channel, so that the gravels in the channel could have been laid down from the overwash of the glacier and should vary in thickness and character according to the manner in which the surface was presented to the glacial discharge. This variation is seen readily on examining the region, as within short distances we find at the same levels erratics and local fragments: rolled here, and locally angular there. Sections show the same variation and disclose the fact that the gravels do not rest on a bottom of uniform level. A number of oil wells have been driven through this alleged river bottom. One of them was a mile from the river and the drive-pipe passed through 50 feet of gravel underlaid by the same thickness of quicksand. The bottom of the pipe was therefore about 50 feet above present water level of the Allegheny. Wherever thick sections can be studied they present strata parallel to the old contours except in a bar laid in the southern part of this alleged channel, which rises on all sides from the average level of the filling, and its strata lie parallel to its surface.

There are many other facts which can not be brought forward in small compass, such as the difference in levels of local deposits on opposite sides of the valley, etcetera, which, combined with what had been given above, show that two short side valleys rise on opposite sides of a low col and debouch into the Allegheny gorge within a mile of one another, and in glacial times these two valleys were filled by overwash deposits mingled with material from the immeiately adjacent slopes.

The next paper was presented without discussion:

APPARENT UNCONFORMITIES DURING PERIODS OF CONTINUOUS SEDIMENTATION

BY G. B. SHATTUCK

The last paper of the day was the following:

*ORIGIN AND AGE OF AN ADIRONDACK AUGITE SYENITE**

BY H. P. CUSHING

[*Abstract*]

Recent field work has shown that there is a great body of eruptive rocks in the heart of the Adirondacks comprising gabbros, anorthosites, syenites, and granites which grade into one another and represent outflows from a common source, not widely separated in time. The order of eruption was anorthosite, syenite, granite, and gabbro. Analyses were presented showing many intermediate types. These intrusives are younger than the sedimentary gneisses of the region and than some of the igneous gneisses also. All show some differentiation *in situ*, though of not great amount. The syenite proves to be a most important rock in the region, occupying an area equally as great, if not greater, than does the anorthosite. It ranges toward the anorthosite on the one hand and toward the granite on the other, all intermediate varieties being found. Much of it was porphyritic and now occurs as an augen gneiss, whose eruptive nature and original structure are perfectly apparent. There is also in the region much thoroughly gneissoid rock, of the same general appearance and composition, which is often closely involved with other sorts of gneiss. This may be in part older, though no evidence is yet at hand which would seem to indicate that this is so. In the absence of such, the author's present disposition is to group all together, accounting for the differences as due to variation in the severity of metamorphism from place to place.

The paper was discussed by J. F. Kemp, A. P. Coleman, and the author, and will be printed as a bulletin of the New York State Museum.

The Society then adjourned. No evening session was held, but the Fellows of the Society, with a few guests, had the annual dinner at Keeler's hotel. The address of welcome, deferred from the opening session, was made by Doctor T. Guilford Smith.

Session of Friday, December 28

The Society met at 9.30 a m, President Dawson in the chair.

The report of the Council was taken from the table and adopted without debate.

* This paper is presented by permission of the state geologist.

The Auditing Committee reported that the Treasurer's accounts had been found to be correct, and the Society adopted the report.

The Committee on Photographs submitted the following report, read by the Secretary:

ELEVENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

During the past year the collection of photographs belonging to the Geological Society of America has been increased by 120 views contributed by the Director of the United States Geological Survey. They are described in the list below. These prints have not yet been delivered, but they will soon be ready. Most of them are to be mounted on muslin for economy in bulk. No offers of prints have been received from other members of the Society.

The collection now numbers 2,033 photographs, which are carefully stored in the Geological Survey building and easily accessible. It contains a large amount of valuable material, and every year a moderate number of copies are ordered for illustrations for text-books and various other educational purposes. It is to be regretted that more extensive use is not made of the collection.

Members of the Society are requested to make additional contribution, but it should be carefully selected so as to include only views which clearly illustrate geologic features or phenomena of general interest, for the collection now contains 15 or 20 per cent of material which the committee does not regard as of general interest or likely to be useful for geological illustrations. The collection would be greatly benefited by the elimination of such views.

The suggestion is offered that during the coming year a complete list of the photographs be published as a brochure of the Bulletin. It would be a reproduction of the lists which have been included in the Proceedings for the last ten years, but it is believed that such a publication, with classified subject index, would greatly increase the usefulness of the collection.

Respectfully submitted. N. H. DARTON,
Committee.

REGISTER OF PHOTOGRAPHS RECEIVED IN 1900

Presented by the United States Geological Survey

Seven $6\frac{1}{2} \times 8\frac{1}{2}$ photographs, by C. D. Walcott

(657). Lower Paleozoic section in cliffs, north side of canyon, north fork of Dearborn river, Lewis and Clarke county, Montana.

(659). Carboniferous limestone cliff of mount Dearborn, north fork of Dearborn river, Lewis and Clarke county, Montana.

(670). Haystack butte from the east, with hay ranch in the foreground. A typical volcanic neck.
(673). Mount McDonald from the east, Mission range, Montana.
(674). Glaciers on Mission range, southeast of mount McDonald, Montana.
(629). Eroded, cross-bedded Cretaceous sandstone, north of the north fork of Sun river, 1 mile east of Rocky Mountain front, Teton county, Montana.
(629). Eroded, cross-bedded Cretaceous sandstone, north of north fork of Sun river, 1 mile east of Rocky Mountain front, Teton county, Montana.

Eight 8 x 10 photographs, by C. Whitman Cross

(453). Granite cut by veins of quartz, feldspar, and biotite. In the canyon of Animas river, opposite Tenmile creek, Colorado, on railroad track.
(465). View of Silverton from toll road, at east base of Sultan mountain. Shows Animas flood plain, mouth of Mineral and Cement creeks, etcetera, Colorado.
(473). From bench (with cabin) at 11,000 feet, on north side of McIntyre gulch, looking across Red Creek valley, southeast. Shows landslide topography of ridge, north of Corkscrew gulch, Colorado.
(475). From knoll near cabin, at mouth of Galena Lion gorge, looking east across Red creek. To show details of landslide topography on slope between Corkscrew gulch and Red mountain, Colorado.
(481). View from knoll at mouth of Gray Copper gulch, looking north down length of Ironton park, Colorado. Saratoga mine buildings on the right.
(483). From bench at 11,500 feet, north of Full Moon gulch, Colorado, looking down valley of Red creek. Cliffs on San Juan tuff on the left.
(485). Rock glacier of Silver basin. From talus slope on east side of basin. Shows relation of glacier to basin. Caribou mine, Colorado.
(488). Putoise peak from Silver basin, looking north across Canyon creek, Colorado.

Eleven 8 x 10 photographs, by N. H. Darton.

(754). Sandstone dike, southeast of Maitland, in Benton shales. Black hills, South Dakota.
(746). Beecher rocks. Erosion in pegmatite, south of Custer, South Dakota.
(780). Oligocene cross-bedded gravel in railroad cut, south of Fairburn, South Dakota.
(740). Devils tower from south.
(736). Devils tower from a mile south; shows base.
(738). Devils tower; near view.
(739). Devils tower, west side; near view.
(745). Columnar structure of phonolite. Inyankara mountain, Crook county, Wyoming.
(748). Overturned tree, with roots lifting rock fragments. West side of Black hills, Weston county, Wyoming.
(742). Sundance mountain; showing talus cones of trachyte near Sundance, Wyoming.

(779). Dakota and Lakota sandstones through upper gateway to Perry park, south of Denver, Colorado.

Twenty-three 6½ x 8½ photographs, by Bailey Willis

(163). Columbia valley, Washington, southeast of lake Chelan; looking northeast across the river to the terraces of Pleistocene age and the high plateau of Miocene basalt.

(167). Navarre coulee, lake Chelan, Washington. Torrent wash due to cloudburst on granite slopes in arid climate.

(182). Lake Chelan, Washington, exhibiting the canyonlike gorge which the lake occupies.

(183). Lake Chelan, Washington. View northward across eastern end of lake, showing terraces produced during glacial occupation of the lake basin in lakelets between the ice and the land.

(193). East end of lake Chelan, Washington. Detailed view of drift dam, showing cross-stratified sandy clays covered by till, gravel, wash, and turf in ascending succession. Between the till and the cross-stratified sands are pockets of coarse gravels and boulders, which probably correspond to stream channels.

(194). Lake Chelan, Washington, and outlet. General view of the drift dam and the site of Chelan.

(196). Stehekin valley, about 2 miles east of Cascade pass, Cascade range, Washington; showing the profile due to profound erosion followed by glaciation.

Cascade pass, Cascade range, Washington. Basin at the head of Stehekin east of the pass, showing the character of the glacial amphitheaters and the remnants of glaciers still lingering among the heights.

(200). Cascade pass, Cascade range, Washington. View from the summit of the pass, 5,300 feet, southward to the headwaters of Cascade river. The high peaks rise to about 8,800 feet.

(201). Cascade pass, Cascade range, Washington. Cliffs of hornblendic gneiss immediately south of the pass, about 3,000 feet in height, exhibiting vertical jointing.

(202). Cascade pass, Cascade range, Washington. Glacier and basin at the head of Stehekin river.

(204). Basin peak, Cascade range, Washington, north of Cascade pass. View of doubtful lake and slope of the mountain, showing joint systems, which are commonly mineralized.

(207). Cascade pass, Cascade range, Washington. Typical glacier of the northern Cascade range, showing a névé and the incipient ice-stream, with crevasses.

(208). Detail of number 207, showing stratification of the ice and structure of the glacier. Taken from the same point as number 207 with long-focus lens.

(210). Cascade pass, Cascade range, Washington. View from an elevation of about 7,500 feet southeastward down the Stehekin valley. The mountain summits fall into a general plane, which was a lowland of late Pliocene time and is now elevated 8,000 feet above sea and profoundly dissected.

(212). Cascade pass, Cascade range, Washington. A typical glacier of the high Cascades, showing the character of crevassing and terminal moraines.

(216). Lake Chelan, Washington; looking down lake, showing Round mountain and hanging valley of Railroad creek.

(218). Lake Chelan, Washington; looking south across the eastern end of the lake to Lakeside and Chelan butte. A glacial terrace and post-glacial ravine are conspicuous in the front of the butte.

(221). Columbia river, Washington, east of lake Chelan. View down the valley from terrace to 3 miles north of outlet of the lake. Terracing on the east bank of the river is due to the occupation of the valley by a lobe of the Okanagan glacier.

(227). Gravel terraces of stream origin in the delta of Chelan river, at its junction with the Columbia.

(228). Columbia river, east of lake Chelan, Washington, showing sand dunes resulting from floods and sediment of the Chelan river.

(231). Chelan falls, Columbia river, Washington, looking south from near the outlet of lake Chelan. The valley and foreground were occupied by a lobe of the Okanagan glacier, which extended down stream to the even-topped terrace. The terrace is 600 feet above the Columbia, and represents a filling during the Glacial epoch which has subsequently been in large part removed.

(223). Delta of Chelan river, at its junction with the Columbia, Washington.

Sixty-four 4 x 5 Alaska photographs, by F. C. Schrader

(147). Dewey creek, and topography opposite Konsina on the east side of Copper river.

(161). Foothills and mountains on Copper river, above Tasnuna.

(150). Cleve valley from moraine near foot of glacier.

Foot of Woods canyon on Copper river, looking up stream.

(115). Mount Drum in center and Tillman in extreme right. Copper river district.

(120). Looking down the Copper river, showing mountains below Chettyna.

(137). Mount Blackburn, mouth and delta of Chettyna river.

(139). "Stick" natives—family, dogs, house, and fish racks.

(181). On Tasnuna river. Front of Woodworth glacier. Shows topography of moraine-covered ice-front.

(185). Woodworth glacier near foot, where cut by Tasnuna river.

(179). Tasnuna river at foot of First glacier.

(195). On Tasnuna river. Quartz gash veining in blue quartz schist bedrock, ½ mile above canyon; looking north.

(20). Chugatch mountains. Sheep mountain (4,200 feet) and vicinity; on south side of Port Valdes, above Swanport. In right of center is Solomons basin; left of center, mount X (5,000 feet) and Sheep Mountain canyon. From Giant Rock island number 1, looking east.

(52). Valdes and mountains on north; mount West in right. From east beach and foot of delta.

(2). Dyea; mouth of valley and mountains on east. From roadside bluff south of bridge.

(18). Range along north shore of Port Valdes. From Potato point.
(76). Foot of Valdes glacier, showing moraine-covered crevasse ridge topography in ice.
(66). Port Valdes. Pack train (Lowe's) ascending terminal moraine in front of Valdes glacier; looking up.
(72). Valdes glacier. Section of crevasse and ridge; ice topography, with mountains in east 2 miles distant, and elevated serac feeder in right. From Government trail on west edge of glacier, 2 miles above foot, at base of mountains, looking across the glacier.
Looking south from Valdes over glacial delta to Chugatch mountain.
(85 and 86). Summit of Valdes glacier, near Klutena glacier.
(103). Klutena river at Devils elbow.
(100). Silt bluffs on east side of Klutena river. From terrace on west, 150 feet above river; looking across the valley and river.
View across Glacier creek, valley of upper Snake river near Nome.
Anvil Creek valley near Nome. Bering sea and tundra in distance.
Anvil Creek diggings, Nome.
(433). Mountainous topography of Nome River valley.
(438). Snake River valley in vicinity of Nome, showing merging of tundra into alluvium.
(424). Part of Nome tundra, Nome, Sledge island and Bering sea in distance.
(442). Edge of tundra and beach of Nome.
(440). Nome beach diggings.
(443). Nome beach gravels, auriferous ruby sand at base.
(7). Down Gens de Larg river from sand dune; looking south 10 degrees east.
(24). Till Bluff terrace, from north shore of Gens de Larg river, 75 miles above mouth of river; looking north 70 degrees east.
(243). Juneau, from rear edge of town; looking southwest across Castinyas channel to Treadwell mines, on Douglas island.
(249). Faulted graywacke, shale, and sandstone in young rock series; from above camp 41; looking west.
(42). Valley tributary to the Gens de Larg alignment of mountain ridges; from station 4, 112 miles above mouth of river; looking south 80 degrees west.
(107). Lower side of gulch and topography above Green mountain, in the middle of valley, about 180 miles above mouth of river; looking north 40 degrees east.
(113). Dark limestone, with schistosity and quartz, ½ mile above camp 27, 189½ miles above mouth of Gens de Larg river; looking south 43 degrees west.
(58). Gens de Larg rapids, 128 miles above mouth of river; from west bank; looking north 45 degrees east.
(122). Plateau and mountains near head forks, Gens de Larg river; from Fork point, about 7 miles above camp 28, at mouth of Portage creek, or 204 miles above mouth of river; looking north 75 degrees east.
(139). View up Portage creek and canyon, from station 12, near mouth of Portage creek, at about 1 mile above camp 28, 194 miles above mouth of river; looking south 13 degrees west.

(118.) Down Gens de Larg River valley, showing north side from camp 28, at mouth of Portage creek, 193 miles above mouth of river; looking north 75 degrees west.

(119). View down Gens de Larg River valley, south side from camp 28, at the mouth of Portage creek, 193 miles above mouth of river; looking south 65 degrees east.

(174). Mountains of limestone and mica-schist, down north side of Robert creek; from Horace peak, 6,000 feet, on headwaters of Koyukuk river, 652 miles above its mouth; looking north 25 degrees west.

Mountains of limestone and mica-schist, down north side of Rober, creek; from Horace peak, 6,000 feet, on headwaters of Koyukuk river, 652 miles above its mouth; looking south 65 degrees west.

Mountainous region, on headwaters of Koyukuk river.

(220). Beginning of clay and gravel bluffs in Middle fork, Koyukuk river, above mouth of Baker creek, one-eighth of mile above camp 36, 606 miles above mouth of Koyukuk river; looking north 59 degrees west.

(196). Limestone ridge and gully; weathering. On north side of Bettles river, 1½ miles below camp 33, 628 miles above the mouth of Koyukuk river.

(213). Mountains of limestone and mica-schist on east side of Diedrick river, from station 19, on Fault mountain, 5,400 feet; looking south 85 degrees east. Faulting of limestone in right.

(242). Canyons in young rock series, 1 mile below Tramway bar; looking north 30 degrees west.

(229). Sluicing the gold placers by Elsingson party on claim 11, Myrtle creek; looking north 20 degrees east.

(224). Gold-bearing schist, showing cleavage and attitudes of rock in bed of Myrtle creek; looking north 60 degrees east.

Young rock series of sandstone and conglomerate with some lignite, 8 miles above camp 38; looking north 65 degrees west.

(377). Elephant mountain; from 3 miles above mouth of Koyukuk river; looking south 49 degrees west.

(353). View down Koyukuk river, showing low plateau topography, ripple-marks, and native village in distance; 135 miles above mouth of river.

(390). View down Yukon river, showing Nulato plateau, from ¼ mile above edge of flats, on right bank of Yukon, between Koyukuk station and Pickart's coal mine; looking south 45 degrees west.

(370). Up Koyukuk river, showing flats with rock plateau and mountains in rear; 26 miles above mouth of river; looking north 65 degrees west.

(280). Bergman and edge of young rock series plateau. Camp 47, opposite Bergman; looking north-northwest across Koyukuk river.

Five 6½ x 8½ photographs, by H. W. Turner

(9). Monoclinal ridge capped by basalt at north end of Clayton valley, Nevada. (1899.)

(12). Lacustral marls of the Esmeralda formation at the east base of the Silver Peak range south of the Emigrant road, Nevada. (1899.)

(14). Fault surface in the foothills of the Silver Peak range southwest of Clayton valley, Nevada. The rock is rhyolite-tuff. (1899.)
(17). Group of cones formed by the unequal erosion of rhyolite-tuff in the foothills of the Palmetto mountains south of Clayton valley, Nevada. (1899.)
(18). A single cone of rhyolite-tuff from the same locality as number 17, in the foothills of the Palmetto mountains, Nevada. (1899.)

Six 4 x 5 photographs, by J. A. Taff

(31). Recumbent fold in sandstone, Saint Louis and San Francisco railway, south base of Winding Stair mountain, Indian territory.
(31). Recumbent fold in sandstone, Saint Louis and San Francisco railway, south base of Winding Stair mountain, Indian territory. Panorama.
(63). Faulted sandstone and shale, Kansas City Southern railway, 1 mile southeast of Houston, Indian territory.
(64). Faulted sandstone and shale, Kansas City Southern railway, 1 mile southeast of Houston, Indian territory.
(34). Faulted sandstone and shale, Kansas City Southern railway, 1 mile southeast of Houston, Indian territory.
(35). Faulted sandstone and shale, Kansas City Southern railway, 1 mile east.

The suggestions in the report of the Photograph Committee were discussed by several Fellows, and it was voted to accept the report and to refer the suggestions to the Council for report to the Society the next day.

The first paper of the scientific program was

LAURENTIAN LIMESTONES OF BAFFINLAND

BY ROBERT BELL

[*Abstract*]

The discovery of great quantities of crystalline limestones in Baffinland was announced in the writer's summary report for 1897. Geographical position and physical aspect of the region described. General character of the Laurentian system in Hudson straits. The rocks of the north side are newer or Upper Laurentian, as far as known, and differ from those of the south shore. Regularity of strike and dip. Enormous development of crystalline limestones in southern Baffinland. Their general characters. Great thickness of the beds, some of them being over a mile and running regularly for long distances. Evidently stratified aqueous deposits. Questions as to the origin of such limestones. The associated rocks and minerals. Owing to the absence of trees, the limestones are conspicuous in the landscape. Not more eroded than the gneisses. Comparison with Laurentian limestones elsewhere. Former physical conditions and the older and newer glaciations of Baffinland as affecting the limestones. The existing glaciers there.

The next paper was

STEREOGRAPHIC PROJECTION IN MAP CONSTRUCTION

BY SAMUEL L. PENFIELD

The two following papers were read by title:

KEEWATIN AREA OF EASTERN AND CENTRAL MINNESOTA

BY C. W. HALL

KEWEENAWAN AREA OF EASTERN MINNESOTA

BY C. W. HALL

These papers are printed as pages 313–342 and 343–376 of this volume.

The following paper was read by the senior author:

PALEOZOIC LIMESTONES OF KITTATINNY VALLEY, NEW JERSEY

BY H. B. KÜMMEL AND STUART WELLER

The paper was discussed by M. R. Campbell, N. S. Shaler, J. M. Clarke, and J. F. Kemp. It is printed as pages 147–164 of this volume.

The last paper of the morning session was the following:

SILURIAN AND DEVONIAN LIMESTONES OF TENNESSEE AND KENTUCKY

BY AUGUST F. FOERSTE

This paper is printed as pages 395–444 of this volume.

A recess was taken for lunch.

The Society reconvened at 2.30 p m, with Vice-President Walcott in the chair.

The paper of Doctor Foerste, read before the recess, was taken up for discussion, and remarks were made by M. R. Campbell, H. S. Williams, A. W. Grabau, and N. S. Shaler.

The next paper was not read, but an abstract presented in the form of the following remarks:

POINTS INVOLVED IN THE SILURO-DEVONIAN BOUNDARY QUESTION

BY H. S. WILLIAMS

[*Abstract*]

The differences of opinion which have been expressed regarding the place in

the New York and other sections of America where the Siluro-Devonian boundary should be drawn are of three kinds, namely:

(1) Matters of fact.
(2) Matters of interpretation.
(3) Matters of usage.

(1) The paleontologic facts regarding the resemblance of the Lower Helderberg faunas to Devonian faunas have been thoroughly presented. The facts regarding the resemblance of the Chapman fauna to the standard Tilestone (Silurian) fauna of Europe have been announced, but have not been fully described or illustrated, and therefore are not open for general discussion.

(2) The questions of interpretation are dependent on knowledge of the facts, and while there is difference of opinion at the present time, the author believes this is due chiefly to comparative ignorance on the part of all concerning the Upper Ludlow and Tilestone faunas of Europe and their supposed equivalents in America. Until the facts can be brought to the knowledge of all parties interested, discussion is not likely to result in correct conclusions.

(3) Matters of usage (namely, nomenclature and classification) are dominated by the fundamental principle of priority. The first scientifically defined name or classification is entitled to take precedence of all new names and classifications until the old one can be shown to be wrong. Established usage in names and classifications is assumed to be correct until its error is scientifically demonstrated. The burden of proof is with those who criticise. New names are not entitled to a place in science unless they are names for new facts. A geological formation belongs in the generic group of formations in which, by common usage, it has been included until sufficient reason can be shown for excluding it.

In consideration of these points, the author urges geologists to refrain from changing established usage regarding the position of the Siluro-Devonian boundary in American rocks until the facts regarding the relationship of the newly discovered Chapman fauna to the Tilestone fauna of Europe can be properly presented to paleontologists for their judgment.

The following paper was read by the author:

KNOYDART FORMATION OF NOVA SCOTIA

BY H. M. AMI

Remarks were made on the paper by H. S. Williams, N. S. Shaler, and the author. The paper is printed as pages 301–312 of this volume.

In the absence of the author, the following paper was read by title:

*AGE OF THE COALS AT TIPTON, BLAIR COUNTY, PENNSYLVANIA**

BY DAVID WHITE

The Tipton Run coal mines of Blair county, Pennsylvania, are located at the forks of one of the deep V-shaped ravines heading westward against the Allegheny escarpment about half way between Tyrone and Altoona. The escarpment in this region consists, according to the measurements of Franklin Platt,† of 2,560 feet of

* The author of this paper does not approve of the rule of non-capitalization of species names when derived from proper names, adopted by the Society.—Ed.

† Second Geol. Survey of Pennsylvania, Report I, Blair county, 1881, pp. 7–29.

Catskill, resting on 4,007 feet of Chemung, and succeeded by 500 feet of greenish grayish and brown sandstones and shales, with green and red shales, of the "red Pocono," about 800 feet of more or less massive sandstones of the "gray Pocono," about 300 feet or less of the Mauch Chunk red shale with its interbedded limestones, greenish sandstones and shales, and by nearly 200 feet of the Pottsville formation, at the base of the Coal Measures. The gray Pocono forms the main front or brow of the escarpment with its high terrace spurs, while the conglomerates of the Pottsville form the crest knobs and scalp-terrace. The dip of the formation decreases from 30 degrees in the valley to 8 or 12 degrees in the Pocono, and a very slight inclination to the west at the upper levels of the mountain.

The mines lie well up in the Tipton ravine, in a low spur between the upper forks of the run, about 500 feet above Tipton station and 790 feet below the crest of the Allegheny front, or about 1,012 feet below Bear Pen point 1 mile to the west of the west (Loop Run) mine. Within a stratigraphical interval of 100 feet five coals, from 1½ to 3½ feet in thickness, were reported by Mr C. S. d'Invilliers. Two at least of these coals have been mined, the output reaching in 1888 a limit of 50,000 tons. One mine is still somewhat extensively operated for country use. The fuel, chiefly from coals "B" and "C," is a low bituminous coal with, according to two analyses by McCreath, about 58 to 66.88 per cent of fixed carbon.

Owing to the juxtaposition and generally similar attitude of the coal-bearing terrane along the strike of the gently westward dipping Pocono, the coals in question have been regarded by the state geologists of Pennsylvania as merely dilations of some of the many thin seams occurring in the contiguous Pocono. Comparisons have been made with the group of coals occurring among the sandstones and shales of the lower Pocono at Sideling hill, Duncannon, and Pottsville, and more especially with the thick and valuable beds mined along Toms creek and in Brushy mountain, in southwestern Virginia. The Tipton Run coals have therefore almost universally been referred to the carbonaceous group in the lower portion of the Pocono, with which they are supposed to be longitudinally continuous.

As the result of an examination of some plants at the Tipton mines the true age of the coals was recognized and announced in 1883 by I. C. White,* who referred them to the Allegheny series, the next group higher than the Pottsville. This correlation of the beds with the productive Coal Measures, whose nearest outcrop—on the mountain top nearly 2 miles distant—is not less than 1,400 feet higher stratigraphically, was quite contrary to the conclusions reached after a special examination by Mr Ashburner in 1885,† and led to a reinvestigation of the subject by the state geologists. The latter, discounting both the paleobotanical testimony and the evidence of the lithology, again affirmed the indisputably Pocono (basal Lower Carboniferous) age of the coals and published them as such in the final report ‡ and in the maps issued by the state. In view of the circumstances narrated, attention deserves to be called again to the correct determination of the age of these beds by Doctor White, though the evidence adduced by the latter, being in itself amply sufficient as proof, should scarcely require reiteration or amplification.§

* Amer. Geologist, vol. iv, July, 1883, pp. 25-32.

† Ann. Rept. Second Geol. Survey of Pennsylvania, 1885 (1886), pp. 250-268, with 2 maps.

‡ Summary Final Report, vol. iii, pt. i, 1893, pp. 1679-1695.

§ Doctor White's conclusions as to the identity of the Tipton with the Clearfield County coals were reached wholly independently and without knowledge of the similar views earlier published by Mr J. W. Scott in the Tyrone Herald. Mr Scott appears to have been the first to recognize the true age of the Tipton Run coals.

From the roof of the coal mined at the time Doctor White obtained nine forms, listed by him as follows: *Pecopteris* sp., *Alethopteris ambigua* Lx., *Alethopteris* sp. allied to *A. pennsylvanica* Lx., *Neuropteris tenuifolia* Brongn., *N. loschii* Brongn., *Calamites* sp. allied to *C. Suckowii* Brongn., *Lepidophyllum lanceolatum* Brongn., *Stigmaria ficoides* Brongn., and *Cordaites gracilis* Lx. By all paleobotanists these species will be recognized as clearly indicating an Upper Carboniferous stage. Further, Doctor White, whose experienced eye recognized the lithological characteristics of the Allegheny series in the Tipton Run terrane, measured up a section 125 to 145 feet in extent, which was regarded by him as including a sandstone, probably of the Freeport group, and 10 feet of Pottsville conglomerate. The principal mined coal from which the fossils were obtained was considered by him, largely on account of its structure and position in the local sequence, as probably the Lower Kittanning.

Another collection of fossil plants was made by Mr Koch, one of the aids of the state survey, at the time, 1889, of the next examination of the Tipton beds by the state geologists. The fossils were sent for determination to the late R. D. Lacoe, of Pittston, Pennsylvania, whose list is printed in the Summary Final Report of the State Survey.* Mr Lacoe promptly reported: "Of the twenty-five species from Tipton, all but four are common in the Coal Measures of North America. This gives a distinctly Coal Measures position to the collection." The state geologists, with equal punctuality and confidence, again referred the beds to the Pocono.

In 1899, during a brief stop of two hours at the Tipton mine, a search for fossils was made by the writer about the largely disintegrated rock dump at the Tipton Run tunnel. The species collected are:

Pseudopecopteris squamosa (Lx.)
Pecopteris vestita Lx. var. *minor* D. W.
Pecopteris miltoni Artis.
Neuropteris scheuchzeri Hoffm.
Neuropteris capitata Lx.
Neuropteris ovata Hoffm.†
Aphlebia sp. indet.
Asterophyllites equisetiformis (Schloth.) Brongn.
Sphenophyllum emarginatum Brongn.
Lepidophyllum stantoni Lx.
Lepidophyllum Mansfieldi Lx.
Lepidophyllum cf. *Lepidostrobus geinitzii* Schimp.
Cardiocarpon cf. *simplex* Lx.
Rhabdocarpos mamillatus Lx.
Estheria sp.

The composition of the flora listed above is characteristic of the Allegheny series. Several of the species occur at some localities in beds as old as the uppermost Pottsville, but the Cardiocarpon is the only form that ordinarily belongs more properly to the Upper Pottsville. *Pecopteris miltoni*, *Lepidophyllum stantoni* and *Rhabdocarpos mamillatus* are seldom to be found below the Kittanning group in the Allegheny series but prevail a little higher, while *Pseudopecopteris squamosa*, *Pecopteris vestita* var. *minor*, and *Lepidophyllum mansfieldi* appear to point toward a level hardly so high as the Freeport. On the whole the flora, with the possible exception of the Cardiocarpon, is, on the one hand, distinctly post-Pottsville, while lacking, on the other side, the later elements which appear in the Freeport group of the Allegheny and in the Conemaugh series. It is characteristic in general of the middle or upper middle portion of the Allegheny series, and appears to indicate an horizon in the

* Vol. III, pt. I, pp. 1691, 1692. I have not been able, after persistent efforts, to locate this collection, which appears to have been lost.

† Includes the plant identified by Doctor White as *N. loschii* Brongn., together perhaps with *N. tenuifolia* of the former list.

Kittanning group. The evidence of the plants collected by the writer appears therefore to agree approximately with Doctor White's identification of the coal with the Lower Kittanning. Besides noting the somewhat characteristic bony bench of the bed described by Doctor White, mention should also be made of the presence in the roof shales at Tipton of small nodular ferruginous sheets such as are found over the Lower Kittanning coal at Benning, Glen White, and the Baker mines.

As further confirming the Coal Measures age of the terrane a few of the species in the Koch collection listed by Lacoe may also be mentioned. Such are the *Annularia sphenophylloides* (Zenk.) Gutb., *Sphenophyllum oblongifolium* Germ.,* *Neuropteris plicata* Sternb., *N. desorii* Lx., *N. clarksoni* Lx., *N. vermicularis* Lx., *Linopteris obliqua* (Bunby), *Pseudopecopteris cordato-ovata* Weiss, *Cardiocarpon bicuspidatum* Sternb., *C. orbiculare* Newb., and *Trigonocarpum triloculare* Hild. The plants cited above seem to indicate more than one horizon of the Coal Measures, and it is probable that not all were obtained from the same bed. Thus the seeds characteristic of the Upper Pottsville were perhaps obtained from an old drift in a lower bed south of the tunnel, or from a lower bed in the tunnel itself. *Neuropteris clarksoni* and *Linopteris obliqua*, while common in the Freeport group. are rare, especially so the latter, in the Kittanning. *Neuropteris vermicularis* and *N. desorii*, on the contrary, belong in the middle and lower portions of the Allegheny series—that is, in the Kittanning and Clarion groups. All paleobotanists and most paleozoologists will recognize the Tipton flora as a typical Coal Measures flora.

The flora of the Pocono, as now revealed by many collections made along the Appalachian trough between New York and Tennessee, is a Triphyllopterid-*Lepidodendron corrugatum* flora. It contains, so far as I have been able to observe, not a single species of vascular plant that is present in the Allegheny series. In fact the flora of the Pocono is so strikingly dissimilar, both in composition and in rank, to that (Allegheny) found at Tipton run as to render the two floras readily distinguishable to any paleontologist who has given the plants of the two formations so much as a casual examination.

The validity of Doctor White's correlation of the Tipton coals with the Allegheny series being incontestible, it is interesting to discover the character of the faulting. The observations made by the writer last summer during a half day about the mines, although incomplete, show that the problem is apparently simple, when once search for a fault is made. A map by Mr d'Invilliers, showing the geographical relations of the mines, to which reference is here made, was published by Ashburner in his 1885 report,† and was reprinted in reduced form in the Summary Final Report of the State Survey.‡

One-half mile west of the mouth of the Gates drift, Tipton Run side of the spur, a good coal is reported from a shallow bore hole, which is evidently in Coal Measures. A few rods westward, however, the terrace of westward dipping shales and sandstones abuts against a knob of the green and red sandstones and shales of the somewhat disturbed Lower Carboniferous. From this point, which is not far from the northern border of the Tipton coalfield, the fault, which follows a slight depression obliquely crossing the low spur between Tipton and Loop runs, is

* Probably a doubtful identification.

† Report on the Tipton Run Coal Openings, Blair county (Coal beds in the Pocono formation, no. X). Ann. Rept. Geol. Survey of Pennsylvania, 1885 (1886), pp. 250-285.

‡ Vol. iii, pt. i, 1893, pl. ccxiii (A), p. 1646.

readily followed in a direction nearly south 10 degrees east to a point on the west side of Loop run about 200 yards southwest of the Loop Run slope, where coal in bad condition was shafted almost directly against the lower Pocono red shales. The southeast boundary of the fault appears to coincide with the transverse valley in which Loop and Tipton runs converge and unite.

The sequence of the formations is well shown in the south point of the low spur-ridge between these runs. At the extreme southeast, above the valley bottom, the green and red shales and sandstones of the Mauch Chunk appear, while in passing along the track of the old railway up Tipton run the Carboniferous limestone in the upper part of the Mauch Chunk presents itself. Above this are characteristic Mauch Chunk beds up to the massive lower conglomerate (Olean) of the Pottsville formation. The ledges of the Pottsville diagonal through the steep southeast slope of the spur, and form the rugged crest point of the latter. The lower conglomerates cross Tipton run near the old commissary site, but the upper part of the formation does not reach the valley level until near the tunnel. It seems probable that the lower prospect drift a short distance south of the tunnel is in this formation, and it is possible that some of the fruits collected by Koch were obtained at this point.

No attempt was made by the writer to trace the eastern border of the coalfield. The strike of the Pottsville near the point of the knob is nearly north 10 degrees east, the dip, as determined by d'Invilliers, being 12 degrees west. On crossing to the east of the run the Pottsville sandstones appear to swing still farther to the north, while flattening somewhat so as to form the long gradual rise to the eastward. Such a swing appears to be indicated not only by the topography, but by the attitude of the coal at the head of the Gates drift, whose local dip is south 60 degrees west. The series of several coal provings ranging from this drift to a point about 2,700 feet north of the Tipton tunnel are probably near the line of general strike, and may all lie within the Allegheny series. The line where the gentle grade of the Coal Measures abuts against the somewhat abrupt escarpment of westward dipping sandstones of the upper ("gray") Pocono is not far from the farthest of these provings. The Pocono escarpment is bold and strong, extending along the northwest side of the coalfield depression and meeting the Pocono spur, first mentioned, on the west of the coalfield.

Although the eastern boundary has not yet been located, it is probable that, as might be expected from the attitude and age of the beds, the Tipton Run coalfield consists of a faulted block which includes at least a portion of the Mauch Chunk shales and sandstones with the Carboniferous limestone, the Pottsville and the Allegheny series, if not higher terranes of the Coal Measures. The block is somewhat warped, as well as slightly shattered, so that toward the east the strike of the Coal Measures is at a wide angle to that of the adjacent Pocono. The minor northwest-southeast faults, described by the state geologists as occurring in the mines and compared by Lesley with the transverse faults at Orbisonia and Three Springs, in Huntington county, or in the Houtzdale-Osceola district of Clearfield county, presumably belong to the same system as the great transverse faulting of the coalfield itself. The stratigraphic displacement of the coal at the Loop Run slope, which, according to Franklin Platt, should be within 200 feet of the base of the Pocono, is probably about 1,550 feet.

The following paper was presented in abstract by W. B. Scott.

A DEPOSITIONAL MEASURE OF UNCONFORMITY

BY CHARLES R. KEYES

The paper is printed as pages 173–196 of this volume.

The two following papers were read by title:

COMPARISON OF STRATIGRAPHY OF THE BLACK HILLS WITH THAT OF THE FRONT RANGE OF THE ROCKY MOUNTAINS

BY N. H. DARTON.

[*Abstract*]

After several years of detailed investigation of the stratigraphy of the Black hills in South Dakota and Wyoming, a preliminary examination has recently been made of the region southwest to and along the front ranges of the Rocky mountains across Wyoming and Colorado. The Black hills are due to a local expansion of a branch of the Laramie range, but the connection underlies a country in great part covered by Tertiary deposits. In the vicinity of Hartville, about 125 miles southwest of the Black hills, there is a local uplift on this line, affording extensive exposures of formations from the crystalline schists part way up the Mesozoic column. The stratigraphy is here very similar to that of the Black hills, and all the principal formations from Lower Cretaceous sandstones to the Lower Carboniferous limestone can be distinctly recognized. Along the flanks of the Laramie range and southward into Colorado the formations present considerable change, but numerous features of close relationship were observed. In the fine sections at Morrison, west of Denver, there was found an extension of the Purple (Minnekahta) limestone of the Black hills having precisely similar stratigraphic relations in the Red beds and containing some of the same Permian fossil, although these are scarce and not well preserved. The limestone was traced south for a considerable distance, and found to merge into a sandy bed, which was finally lost in the great mass of coarse red deposits in the vicinity of the Garden of the Gods. Its very distinct occurrence at Morrison affords the means for a precise correlation with the Black Hills region. The underlying mass of coarse sandstone against the crystalline rocks represents portions or perhaps all the Carboniferous formations of the Black hills. The Red beds overlying this Minnekahta limestone at Morrison are gypsiferous shales similar to those of the red valley encircling the Black hills. The Morrison formation lying next above is, as previous observers have pointed out, the equivalent of the Atlantosaurus (Beulah) shales, while the marine Jurassic, which was traced as far south as the Hartville region, is lacking in the Morrison section. The lower Cretaceous sandstone in the Black hills has not been recognized in Colorado. The Benton formation presents the same three divisions through the Black Hills region as were determined by Gilbert in southern Colorado. In the valley of the Purgatoire, in southern Colorado, the Red Bed series is represented by red sandstones of moderate coarseness, in the upper bed of which was discovered a bone of a Bolodont, which is thought to be of Triassic age. The overlying series of gypsum, limestone, and shale yielded no fossils, but probably comprises a representative of

the Morrison formation, for its upper part at least has all the characteristic features of the Atlantosaurus shale. It is overlain by so-called Dakota sandstone.

TERTIARY HISTORY OF THE BLACK HILLS

BY N. H. DARTON

The next paper was read by the author:

MARINE AND FRESHWATER BEACHES OF ONTARIO

BY A. P. COLEMAN

The paper was discussed by Robert Bell, G. K. Gilbert, N. S. Shaler, C. H. Hitchcock, F. B. Taylor, and H. P. Cushing. It is printed as pages 129–146 of this volume.

The following paper was then read:

GLACIAL LAKES OF MINNESOTA

BY N. H. WINCHELL

Remarks upon the subject of the paper were made by the President and Robert Bell. The paper is printed as pages 109–128 of this volume.

The last paper presented during the session was the following:

GEOLOGY OF RIGAUD MOUNTAIN, CANADA

BY OSMOND E. LE ROY*

In discussion remarks were made by F. D. Adams, N. S. Shaler, H. M. Ami, Robert Bell, J. F. Kemp, and the author. The paper is printed as pages 377–394 of this volume.

No evening session was held, but the Society was given a reception by Doctor and Mrs F. J. H. Merrill, at their residence, 95 Washington avenue.

Session of Saturday, December 29

The Society was called to order by the President at 9.45 a m, and the following administrative business was transacted:

RECOMMENDATIONS BY THE COUNCIL

The Council recommends:

(1.) That the Society appoint a special committee with power to eliminate undesirable material from the collection of photographs, and

* Introduced by F. D. Adams.

to publish a list of the collection; such committee to consist of N. H. Darton, J. S. Diller, G. K. Gilbert, and G. P. Merrill.

(2.) That Joseph Stanley-Brown be elected a Life Member in recognition of his services to the Society as Editor.

(3.) That the following resolution be adopted:

"*Resolved*, That recognizing the great historical, scientific, and economic value of the collections of the State Museum in Albany, representing the geology and paleontology of the state of New York, the Geological Society of America expresses an earnest hope that an ample and fireproof building will be provided for the display of these priceless collections where they may be accessible to students interested in the progress of science and in the economic development of the state."

The several recommendations were adopted.

The following resolution of thanks was then passed:

"*Resolved*, That the hearty thanks of the Society be tendered to the Trustees of the Albany Academy for their generous hospitality; to Messrs J. M. Clarke and F. J. H. Merrill for their successful efforts in behalf of the meeting, and to Doctor and Mrs Merrill for the delightful reception of Friday evening."

The first paper of the scientific program was the presidential address:

GEOLOGICAL RECORD OF THE ROCKY MOUNTAIN REGION IN CANADA

BY THE PRESIDENT, GEORGE M. DAWSON

The address is printed as pages 57–92 of this volume.

In the absence of the author, the following paper was presented in abstract by G. P. Merrill:

WEATHERING OF GRANITIC ROCKS OF GEORGIA

BY THOMAS L. WATSON

The paper is printed as pages 93–108 of this volume.

The three following papers were read by the author:

PENEPLAINS OF CENTRAL FRANCE AND BRITTANY

BY W. M. DAVIS

[*Abstract.*]

Three recent articles,* in which the theory of peneplains has been adversely criticised, have taken examples for consideration chiefly from districts which are

* R. Tarr: The peneplain. Amer. Geologist, vol. xxi, 1898, pp. 351–370.
W. S. Tangier Smith: Some aspects of erosion in relation to the theory of the peneplain. Bull. Dept. Geol. Univ. Cal., vol. ii, 1899, pp. 155–178.
N. S. Shaler: Spacing of rivers with respect to hypothesis of baselevelling. Bull. Geol. Soc. Am., vol. x, 1899, pp. 263–276.

FIGURE 1—VIEW OVER THE CENTRAL PLATEAU OF FRANCE

This picture was taken near the village of Védrine, over the valley of the Chavannoux. The plain in the foreground bears waterworn cobbles and pebbles, and is probably the ancient high-level floodplain of the Chavannoux.

FIGURE 2—VALLEY OF THE CHAVANNOUX, IN THE CENTRAL PLATEAU OF FRANCE

The locality is between the villages of Védrine and Eygurande. Ledges are frequently exposed in the valley sides. Narrow floodplains are often formed along the valley floor.

CENTRAL PLATEAU OF FRANCE AND VALLEY OF THE CHAVANNOUX

today maturely dissected to a considerable strength of relief, however perfectly they may have been worn down to lowlands in a former cycle of erosion; and with these examples in mind, alternative explanations have been offered by which to account for the existing forms independent of peneplanation. Tarr's theory of bevelling (to which my response* did, I regret to say, insufficient justice, through misunderstanding of the intended meaning) and Tangier-Smith's and Shaler's theory of the subequality of mature hilltop heights as a result of the subequality of stream spacing are interesting contributions to the general subject of land sculpture, but it does not seem to me that they touch the question in hand closely enough to invalidate the theory of peneplains, inasmuch as they give no sufficient explanation for uplands of relatively even surface, unsympathetic with structure, and only here and there dissected by streams whose valley sides rise steeply to the upland level. Moreover, the forms producible by bevelling and stream spacing are imitated by dissection after peneplanation. What we need is a means of discriminating among the forms of these three origins, rather than an argument for the exclusion of one origin because of the competence of the other two.

Evenly truncated uplands are by no means rare. The four views here presented are all of European localities, not because American examples are wanting, but because my recent excursions have happened to afford illustrations from abroad.

Plate 44, figure 1, is a part of the broad uplands that have been eroded on the crystalline and stratified rocks, all much disordered, of the central plateau of France. The photograph was taken from the village of Védrine, in the neighborhood of a railway junction called Eygurande, where the upland is deeply dissected by the Chavannoux (a northern branch of the Dordogne), whose valley sides, shown in plate 44, figure 1, present numerous bare ledges, while the gently rolling uplands are cloaked with deep residual soils. The particular upland here shown is unusually smooth; water-worn pebbles and cobbles are plentiful at certain points upon it, and it may therefore be considered to represent the floodplain of the Chavannoux in a former cycle of erosion, when the land stood much lower than it now does. The adjoining uplands rise somewhat above this plain and are more undulating than it is. They have deep soils, but no water-worn stones were found on them. Monadnocks are numerous in certain districts, although absent hereabouts. Some of them are rugged, with ledges and boulders on their slopes, almost reminding one of a New Hampshire landscape, although no trace of glaciation has been detected in their locality; others are more subdued, presenting rounded outlines and smooth slopes, imitative of drumlins. Bevelling and stream spacing entirely fail to account for this combination of forms, but the uplands and valleys may be satisfactorily explained by assuming a former cycle of erosion well advanced into old age, followed by a new cycle, introduced by a broad uplift and now in its youth.

Plate 45, figure 1, is from Belle Isle, an isolated part of Brittany, today sharply attacked by sea waves on all sides, so that its margin is cut by strong sea cliffs. Its upland surface is somewhat dissected by valleys, one of which is here shown. The striking feature of this example is the sharpness of the shoulder between the upland plain and the valley slope. The plain is broadly undulating in very gentle relief, well covered with locally weathered soil; the valleys are manifestly the product of a different cycle of erosion from that in which the uplands were produced. Bare ledges of disordered crystalline schists are sometimes exposed on

* The peneplain. Amer. Geologist, vol. xxiii, 1899, pp. 207-239.

the valley sides; but the slopes are more generally of rather even declivity, as if pretty well graded.

Marine abrasion as an alternative to subaerial erosion naturally calls for consideration in the origin of the uplands of Belle Isle, but it is of doubtful application. There are no marine gravels on the uplands, and it is my impression that the depth of upland soil is greater than could have been produced by the action of weather on a sea-planed rock platform during no longer time than was sufficient to erode the narrow valleys; but on this point I have no direct evidence to offer. On the other hand, the peneplain of Belle Isle is very probably of the same origin as that of the mainland of Brittany, where uplands as even as those of the outlying island are common. But here the larger area permits the occurrence of a greater variety of rocks, some of which rise in subdued ridges running east and west through the peninsula. The prevalent occurrence of deep-weathered local soils, the absence of all trace of sea cliffs along the base of the subdued ridges and of the many isolated hills associated with them, as well as the absence of marine gravels along the coastal part of the uplands, where they descend slightly toward the sea (marine deposits occur at lower levels), give strong evidence against a marine origin of the plain, while an origin by bevelling or by stream spacing seems here to find no room for consideration.

So strongly was this conclusion impressed upon me that the thinness of the soil on certain marginal areas of the Brittany peneplain seemed explicable only by a brief and local submergence after subaerial peneplanation, thus allowing the waves to remove most of the weak soil cover, but not giving them time enough to cut a shoreline. An example of this kind is given in plate 45, figure 2, taken from a low hill (Mont Saint Michel—not the famous rocky island of that name) on the outskirts of the village of Carnac near the southern coast. The occurrence of thousands of huge standing stones in the neighborhood of Carnac seems to show that the ancient peoples here took advantage of the partial removal of the soil and of the revelation of countless weathered and loosened ledges in selecting this district for their remarkable monuments. The peneplain is really not so smooth here as in many other districts, however level it looks in the view. It stands close to sea-level and dips under water gently, without being cliffed; an exceptional feature for Brittany. The plain rises gently toward the interior, so that the streams intrench themselves beneath the upland surface and erode valleys whose depth is at a maximum somewhat above the middle of their length.

If arguments are to be advanced against peneplanation, they would seem to me more convincing if land forms of the kind here presented should be considered along with those of more mature dissection; and if several processes are held to be capable of producing even-topped uplands, sharply trenched by narrow valleys, then some means of distinguishing among the forms resulting from the action of the several processes should be devised. Furthermore, inasmuch as it is eminently possible that peneplanation, followed by uplift and mature dissection, may produce forms that will closely imitate those attributed to bevelling and to stream spacing, it is desirable to find particular signs by which the results of the various processes may be discriminated in the later stages of erosion, as well as in the earlier stages above illustrated. It is premature to appeal today to simplicity of process or inferred probability of occurrence in favor of this theory or of that when one is trying to explain land forms that may also be accounted for by any one of several other theories. Simplicity is a strong recommendation, especially in artifi-

FIGURE 1.—UPLAND OF BELLE ISLE

The upland is dissected by flat-floored, steep-sided, dry valleys

FIGURE 2.—PLAIN OF SOUTHERN BRITTANY, NEAR CARNAC

The view is from a small residual hill.

UPLAND OF BELLE ISLE AND PLAIN OF SOUTHERN BRITTANY

cial mechanisms, but it is entirely possible that geological processes may sometimes have been complicated rather than simple. The probability of occurrence of one process or another is the very question at issue, and an *a priori* measure of probability cannot be safely accepted as a guide to the solution of the problem. All that can be done is to deduce certain consequences appropriate to the several theories, and then to discover which of these consequences best match the observed facts. Bevelled hilly regions (regions in which the hilltop height gradually decreases from the interior toward the shoreline) are to my mind better explained by peneplanation (or marine abrasion), uplift, and dissection than by bevelling. Maturely dissected uplands with summits of subequal height (but not slanting to the seashore like bevelled regions) may also be explained by peneplanation (or marine abrasion), uplift, and dissection, as well as by stream spacing; but even-topped uplands, bearing deep soils, extending their flat surface into protected districts among subdued hills, dissected only by narrow, sharp-shouldered valleys, whose arrangement exhibits an adjustment to the rock structures that underlie the deep soils, are accounted for only by peneplanation. It is forms of this kind that have given effective support to the theory of peneplains, and it is particularly to forms of this kind that attention should be directed when the theory is taken up for discussion.

Remarks were made by N. S. Shaler, C. D. Walcott, H. M. Ami, and G. K. Gilbert.

AN EXCURSION TO THE COLORADO CANYON

BY W. M. DAVIS

[*Abstract*]

Observations made in the canyon of the Colorado and over the plateaus on the north and south, during a three weeks' trip in June, 1900, add the occurrence of certain landslides and migrating divides to the evidence already stated by Dutton in favor of two cycles of erosion in the development of the Grand Canyon district, the broad denudation of the plateaus being accomplished in the first cycle and the incision of the narrow canyons in the second. The faults by which the plateaus are divided are regarded as for the most part of greater antiquity than the canyon cycle; the antecedent origin of all the branch streams of the Colorado in this district is questioned; and the high-level floor of the Toroweap valley is explained otherwise than by the failure of its former water supply through a change from a humid to an arid climate.

The paper was discussed by G. K. Gilbert and C. D. Walcott. The full paper is printed in the Bulletin of the Museum of Comparative Zoology at Harvard College, geological series, volume 5, number 4, pages 105–201, May, 1901.

NOTE ON RIVER TERRACES IN NEW ENGLAND

BY W. M. DAVIS

[*Abstract*]

When the title of this paper was sent in for the announcement that was issued prior to the Albany meeting, it was thought that the controlling relation here

considered between rock ledges and river terraces had not before been announced. It has since then been found that the essence of the relation has been stated in a paper by Hugh Miller.* The present note must therefore serve chiefly to make Miller's paper better known to American readers by showing the application of his theory to American examples, as well as to suggest that the plains of our New England terraces do not indicate gradation with respect to temporary baselevels and that the arrangement of terraces in flights of steps does not depend on the diminution of stream volume, however true it may be that stream volume has diminished during the process of terracing.

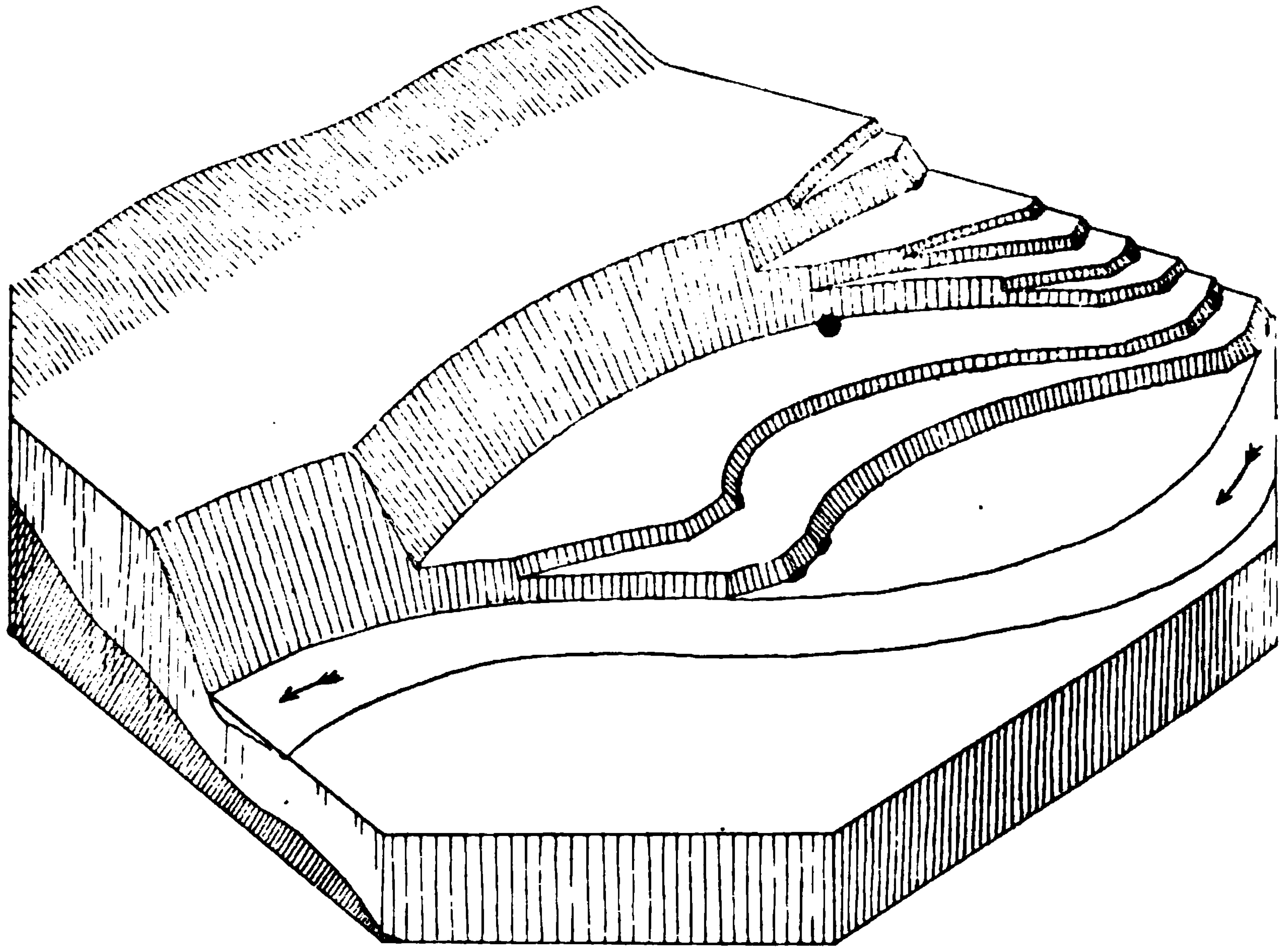


FIGURE 1.—*Block Diagram of River Terraces*

A flight of terrace steps defended by successive outcrops of a long, sloping ledge in the background. A single high terrace formed by the consumption of all the earlier made terraces in the foreground. Two ledge-defended low-level terrace cusps below a high terrace in the center.

In a valley whose cross-section shows several terraces at successive heights, it is necessarily the case that the breadth of the interscarp space between the high-level terraces is greater than that between the low-level terraces. Besides Miller's theory, two others are current for the explanation of this feature. One theory postulates a once greater volume for the terracing river. At first, when large, the river is supposed to swing broadly from side to side and thus open a wide interscarp space; later, when the valley had been eroded to a greater depth and the volume of the stream had decreased, the river is contented with a smaller width

* River-terracing: Its methods and their results, Proc. Roy. Phys. Soc. Edinburgh, 1883, vol. vii, pp. 263–306.

of swinging and the terrace scarps come nearer together. The second theory postulates as many uplifts as there are terraces, and further requires a systematically diminishing time interval between the uplifts, thus allowing the river to open a wide valley floor in the early stage of terracing, but only a narrow floor in the late stage.

Miller's theory is, in effect, that the lateral swinging of the terracing stream is occasionally hindered by the discovery of a rocky ledge or a mass of till in one bank or the other, and that inasmuch as such ledges and till masses must (other things being equal) be more frequently encountered in the later and deeper stages of erosion than in the earlier and shallower stages, it necessarily follows that the scarps of the low-level terraces must be held nearer together than those of the high-level terraces. Where ledges are few the early-made terraces are apt to be undercut and destroyed by the river in forming the later-made terraces, as in the foreground of the accompanying block diagram. Where ledges are numerous, a whole flight of terrace steps may not only be formed but preserved, as in the background of the diagram. A small ledge, exposed for only 5 or 10 feet in the bank of a stream, may restrain the swinging of the stream and thus defend the surmounting terrace for some distance, both up and down the valley. The cusps by which terrace fronts frequently advance into the valley are often determined by ledges. A long sloping ledge may determine a group of cusps, systematically placed one over the other.

A recent examination of the terraces on Saxtons river, near Bellows Falls, Vermont, and on Westfield river, near Springfield, Massachusetts, shows that the terrace fronts there are frequently controlled by ledges and that Miller's theory is closely applicable in explaining them. A fuller account of these and other terraces will be presented in a forthcoming number of the Bulletin of the Museum of Comparative Zoology at Harvard College.

Remarks were made by N. S. Shaler.

The following three papers were read by title without discussion:

WISCONSIN SHORE OF LAKE SUPERIOR

BY G. L. COLLIE

The paper is printed as pages 197–216 of this volume.

LANDSLIDES OF ECHO AND OF VERMILION CLIFFS

BY RICHARD E. DODGE

[*Abstract*]

The northern portion of the Echo cliffs and the Vermilion cliffs along the margin of the Paria plateau exhibits a wonderful series of landslides. The slides occur in the basal layers of the Trias, where they are feebly supported by the underlying Permian, and in some cases have slipped over the edges of the exposed Permian layers, almost shrouding them. The upper cliff, made by the stronger top layers of the Trias, presents a very even front where bordered by the slides, and as yet has contributed but little waste to the surface of the slides.

RIVER ACTION PHENOMENA

BY JAMES E. TODD

Contents

INTRODUCTION

Although the phenomena mentioned in this paper have been alluded to in the writer's previous papers and to some extent by others, he ventures to call more direct attention to them. They have quite important practical as well as scientific value and seem worthy of being more distinctly recorded than they have been.

CUTTING DOWN OF RIVER BOTTOM IN TIME OF FLOOD

The first is the fact that in time of flood the bottom of a river cuts down as the surface rises. It has long been recognized that in floods the slope and velocity increase, and therefore the corrading and transporting power is increased, but the extent to which this is done, especially in streams abounding in sediment, has not been clearly set forth.

We are fortunate in having distinct testimony on this point from experienced engineers. Mr L. C. Cooley, of the United States corps, states that at Nebraska City, "when the river strikes quite sharply against a high bluff, though it ordinarily is but 40 or 50 feet in depth, when it reaches high water it is sometimes 90 feet"—that is, it picks up 20 or 25 feet of sand and gravel at the bottom as it rises 15 or 20 feet.*

At the bridge near Blair, Nebraska, Mr E. Gerber, assistant engineer for the Fremont, Elkhorn and Missouri Valley railroad, watched very closely the cutting of the river to see how it might endanger the bridge which had been quite recently erected. Not only was the gauge read regularly but soundings were taken about every 10 days during the flood, from June 23 to August 18, 1883. It was found that although at very low water the river was only a little over 10 feet deep, when it had arisen 10 feet, it had cut down to bed rock, which was 50 feet below low-water mark.†

Mr George A. Lederle, engineer of the Omaha bridge, reports similar phenomena at that point, but not so completely.

At Blair, Omaha, Platsmouth, and Nebraska City the bed rock is 50, 90, 55, and 85 feet, respectively, below low-water mark, and in every case shows gravel, sand, and clay boulders resting directly upon water-worn rock. Although no observations have been made when the water was cutting below 90 feet, there seems to be no good reason for doubting that in beds and narrow places in the river the bed rock may be sometimes touched below that level, so that in the shifting of the stream the whole bed-rock bottom of the valley from bluff to bluff has been swept

* Report of the United States Engineers, 1879–'80, part ii, pages 1066–1071.

† U. S. Geol. Survey, Bulletin 158, p. 151.

in comparatively recent time. With this well established phenomenon there goes several important corollaries:

1. First, a depth of bed rock 100 feet below present low water does not demonstrate a buried channel. The size of the present stream and its efficiency in time of flood must be known before a conclusion can be reached. Moreover, as the relative softness of rocks influences the rapidity of corrasion in the bottom, as well as on the sides of the trough, greater depths are to be expected where the strata are soft; and, consequently, in the planation of a region by a stream there will be considerable irregularity in the surface of the bed rock underneath the alluvial deposits.

2. In estimating the discharge of streams which have quantities of sand in their trough, like the Missouri and Platte, the height of the water is only one factor, and oftentimes not the most important factor for determining the cross-section of the stream. Doubtless there will be less scouring out of the bottom in a straight course than in a bend, but it would be very considerable, particularly where its narrowness suggests a favorable opportunity for estimating discharge. The Blair bridge is in a comparatively straight part of the Missouri, yet its bottom cut out 30 or 40 feet in time of flood.

3. The transfer of sediment down the valley of a river would be much more rapid than commonly supposed. When the stream is at its full, the scores of feet in thickness of material usually lying quiet in the bottom is moving with nearly the full velocity of the surface of the flood.

4. Recent objects may be buried to a depth of 100 feet within a few years. In the shifting of the Missouri a dozen or score of years may suffice to transfer the deepest point of a bend into dry land covered with ordinary vegetation. If a well were sunk in such a place a brickbat or other recent object might be struck at that depth. This shows how weak are some of the arguments for great antiquity of objects found deeply buried in the alluvium of Louisiana, or the delta of the Nile.

Mutual Flood-relief Channels

When two streams unite which are subject to floods and one or both rich in sediment, there is apt to be found a little above their junction a channel which we will call a *mutual flood-relief channel*. It has long been recognized that when either stream bears sediment, a bar is apt to be formed just above the junction of the currents of the two streams. This may be ascribed mainly to the diminished velocity resulting from the collision and intermingling of currents. The swifter stream is likely to be more heavily laden, and the resulting velocity, when it mingles with the slower current, causes some of the sediment to drop; hence the point separating the streams tends to lengthen; it tends to curve more or less across the slower stream. This curve may be straightened when that stream quickens its current in time of flood; but, since the sediment tends to deposit more rapidly near the current, there is apt to be left a depression separating the elongated bar from the original bank. At times when either stream is in flood and the other low, there is a tendency for the surplus water to break over this sag into the lower stream. This tends to keep it open at the level of high water at least. Sometimes it is cut below low water, so that the bar forms an island. From this explanation it will be seen that the erosion of this channel is especially favored by floods occurring in the two streams at different times and not simul-

taneously. We have stated a general rule. When either stream is without floods the channel may not appear.

One of the first examples to attract the writer's attention was in the high terrace between Swan Lake creek and the Missouri river, Walworth county, South Dakota. Its formation dated back to the Glacial period.*

A good recent example is shown near Fort Snelling, at the junction of the Minnesota and the Mississippi.†

Other ancient examples are found crossing the high terraces above the junctions of Loup fork and Shell creek with the Platte, in eastern Nebraska.‡

Also the junction of the Kansas and Missouri rivers, at Kansas City. The former stream now occupies the ancient flood-relief channel.

Of recent examples, an interesting one is found at the junction of the Big Fork or Bow String with Rainy river, in northern Minnesota; and in Missouri, the junction of the Grand and Missouri rivers, near Brunswick; the Osage and the Missouri, above Dodd island; the Loutre and the Missouri, opposite Herman; the Missouri and Mississippi, above Mobile island. Other cases are less clear, as the Chariton and the Missouri, the Nishnabotna, Tarkio, and Platte with the Missouri. The later are less clear because the Missouri in its windings has cut into their channels. Other examples can doubtless be found without difficulty.

As a result of the foregoing we have the following corollaries:

1. If either stream eventually cuts lower than the other the higher is apt to take the flood-relief channel for its mouth. This change will take place probably in time of flood. In most cases the tributary will be the one taking it. For example, the Kansas river before mentioned. On the other hand, the main stream may sometimes occupy it by having its current thrown through it by the shifting of its bends. This will rarely occur, but seems to have been the case at Vermilion, South Dakota, when the main current of the Missouri came into the Vermilion west of Kidders island about 1860, and again about 1874.

2. It remains to consider whether flood-relief channels may be so persistent as to keep open during the erosion of deep valleys, and thereby produce a high island detached from the promontory above the junction of two streams. We may readily admit that the chances are against it, for the meanderings of the streams about it are likely to destroy such an island: but if there be a very durable rock or rapid currents in the streams, such a result seems conceivable.

Cote Sans Dessein, which is a rocky ridge rising 100 feet above low water in the midst of the valley of the Missouri near its junction with the Osage, may be an example of this sort. It doubtless is a part of the ancient divide between the Missouri and Osage rivers. Its position is favorable to such an explanation; but perhaps it is more likely to be the result of one stream cutting through more recently into the valley of the other, as has been suggested by Mr C. F. Marbut.§ It is evident that the Missouri has encroached upon that side of the valley, as he very clearly shows.

Velocity checked by Overflow, though Slope is increased

A third point is that a flooded stream has its velocity checked by overflowing its

* See U. S. Geol. Survey Bulletin 144, p. 42, pl. xvi. Lower view by a typographical error.

† Part ii of the Report of the Minnesota River, 1874, p. 6.

‡ See Science, March 11, 1892, p. 148.

§ See Amer. Geologist, vol. xxi, p. 86.

floodplain. This was strongly brought out by an investigation of the great flood of the Missouri river in 1881.*

The main facts of the report are given as follows:

"From Sioux City to a point below Glasgow, Missouri" [that is, for 600 miles], "the valley was submerged essentially from bluff to bluff. Between Sioux City and Omaha, between Platsmouth and White Cloud, and between Kansas City and Glasgow, where the valley is much above the average width, the overflow was not very deep, but much of the water flowed off through sloughs and low portions of the valley and did not pass the gauges at all. Near Omaha, from Saint Joseph to Kansas City, and from Glasgow down, the valley is narrow. In the two first mentioned portions the overflow was deep, and the bed proper was disregarded, the river flowing down the center of the valley. Near Glasgow the same was true to a great extent, but between that point and Cedar City the river got between its banks, and from there down there was no overflow of any consequence and no diversion of the water from the bed proper. The latter was quite generally silted up—at least we can infer so from the deposits—from 6 to 12 feet in depth, which were afterwards measured on islands and bars which were sheltered from the fierce currents which set up when the river returned within its banks. Deposits on the bottom lands were enormous in quantity and extent, the immediate banks being raised for long distances from 4 to 6 feet. This afforded a very interesting exemplification of the manner in which the banks of silt-bearing streams are raised above the general level of the country. From Omaha, Saint Joseph, Kansas City, and Glasgow reports were received that after the river got out of its banks the rate of rise increased, while the current was so materially slackened in the course of a few hours that skiffs could row about with ease, although before the river left its banks and after it returned to them the current was so strong that even steamboats were unable to stem it.

"The greatest rises heretofore observed were about 7 feet lower at Sioux City than the one under consideration. Their crests took from 6 to 7 days to reach Saint Charles, while this one took 12 days." [Moreover, this retardation was mainly in the wide portions of the valley.] "Now it is, we think, obvious that these extraordinary results can only be explained by the fact that the river was out of its banks. It was practically transferred from its normal section to one of small depth but miles in width. The slope was about double, but this was not enough to offset the immense increase of frictional resistance. Consequently the freedom of flow was so greatly checked that the water in the rear piled up on that in front and produced the abnormal rise.

"Any fill which took place in the bed proper during the overflow was pretty much scoured out on the falling stage, after the river got within its banks again. From all points it was reported that during this period the force and velocity of the current were extraordinary. Bars which had been permanent fixtures for years were removed; and a general deepening was noted on all sounded sections; but on islands and bars which were sheltered from this great scour the depth of the deposits gives sufficient evidence of the extent to which fill took place during the overflow. It was thought that the effect of the flood would be to leave permanent deposits which would affect the low-water plane, but such does not seem to have been the case." †

This possibility of a river putting on lacustrine conditions while its slope is much increased is not only surprising but has several important bearings.

1. It explains the common loam or silt capping extensively bottom lands and terraces. To be sure, ordinary overflows tend in the same direction, but they are evidently incompetent to produce the deep loam uniformly covering all such regions. This loam is found not only deeply covering the bottom lands of the Missouri, but also the high terraces of the Glacial epoch. Upon the latter it is found frequently more than a dozen feet in depth and sometimes reaches a depth of 30 feet. The latter depths are found not far below the mouth of the Cheyenne river, and Doctor Hayden in his report seems to have classified them with his "calcareous marl" or "loess," which he says extends along the Missouri to that point. The low-level loess at Saint Joseph, Kansas City, and Glasgow, Missouri, may be

* Report of the Mississippi River Commission, 1881, p. 136.

† Missouri Geological Survey Report, vol. x, p. 207.

easily accounted for by such a flood, on a grander scale, attending the melting of the ice-sheet of the Wisconsin stage in Dakota.*

2. It is not difficult to extend the analogy also to the streams draining the ice-sheet at the end of the Kansan stage of the Glacial epoch, and thus explain the vastly wider silt-sheets, known as loess or "upland loess." Such a view will go farther toward explaining the massive structure, the wide stretches of flat surface, and yet considerable range of level of that problematic deposit. Of course, we would not be suspected of ignoring the results of subsequent erosion and creeping, nor of the frequently important influence of æolian action.

3. We have in this phenomenon another obstacle to the easy calculation of the discharge of rivers by simply noting the rise of water upon gauges; for the channel is vastly widened, so that the gauge ceases to be the proper measure of the cross-section on that account. But a still more important difficulty results from the temporary filling of the regular channel. This is likely to be overlooked, and yet the fact of its occurrence seems clearly established. The great flood of 1881 was doubtless exceptional in degree, yet it shows the working of conditions efficiently present in any flood where the water overflows the banks. It will be noted that this tendency is in the opposite direction of the phenomenon first noted in this paper. It seems that as long as the water remains in the banks a flood cuts out at the bottom of the channel, but as soon as the water begins to overflow, especially when a considerable current begins to traverse the bends of the stream, the flow in the channel proper is checked and rapid deposition begins; hence the discharge of water will be much less than would be inferred from the reading of the gauges.

The following paper was read by the author:

FORT CASSIN BEDS IN THE CALCIFEROUS LIMESTONE OF DUTCHESS COUNTY, NEW YORK

BY W. B. DWIGHT

[*Abstract*]

Hitherto, in the large and unique assemblage of fossils of the Calciferous limestone of Dutchess county, New York, no special relations to the remarkable fauna of the Upper (?) Calciferous beds of Fort Cassin, Vermont, have been discovered, unless in the relative abundance and prominence of cephalopods.

This is easily explained by the fact that the characteristics of the Dutchess County cephalopods, especially the frequency of the septa, and the complicated forms of the septal necks show that the main Calciferous beds (conveniently designated the Cyrtoceras vassarinum beds) of Dutchess county are much older than the Fort Cassin beds.

A recent careful study reveals the presence in Dutchess county of a layer quite persistent throughout the nearly 30 miles of extent of fossiliferous calciferous strata, which contains a peculiar fauna entirely differentiated from the fauna of the main or Cyrtoceras vassarinum beds. It is, in places, absolutely crowded with fossils, largely fragments of small trilobites, but it lacks cephalopods almost entirely.

* Missouri Geological Survey Report, vol. x, p. 207.

There are no important fossils in common in the two beds, except two or three which are generally found in all calciferous fossiliferous beds.

On the other hand, this layer is plainly related to the Fort Cassin beds in the presence of the *Asaphus canalis* and *Syntrophia lateralis* of those beds in abundance, and also probably of *Lophospira cassina*. The stratigraphic relations of this layer are as yet quite uncertain. The confused condition of the greatly folded and faulted strata of Dutchess county have made it impossible to determine them as a question of superposition. Its relations to the Fort Cassin beds seem to place it above the Cyrtoceras vassarinum beds, in view of the more ancient types of the latter over those of Fort Cassin; yet the presence of quite a number of black linguloid fossils resembling *Lingulepis pinniformis*, which do not occur in the *vassarinum* beds, suggests a lower stratigraphic position.

As there is much doubt about the true horizon of the Fort Cassin beds, the results of further investigations in that vicinity will have an important bearing on the stratigraphic relations of this Dutchess county layer. It differs remarkably from the Fort Cassin beds in the extreme scarcity of cephalopods.

Remarks upon Professor Dwight's paper were made by C. D. Walcott.

The next paper was read by title:

MIOCENE FAUNAS OF PATAGONIA

BY W. B. SCOTT

The following paper was read by the author:

GLACIATION OF THE WESTERN PENINSULA OF ONTARIO

BY F. B. TAYLOR

Remarks were made by W. M. Davis and A. P. Coleman.

The next paper was also read by the author:

DEVELOPMENT OF THE BASAL ARMS OF CERTAIN CRINOIDS

BY A. W. GRABAU

Remarks were made by H. M. Ami and W. M. Davis.

The three remaining papers of the program were read by title.

THE ATCHISON DEEP WELL

BY ERASMUS HAWORTH

SAND CRYSTALS AND THEIR RELATION TO CERTAIN CONCRETIONARY FORMS

BY E. H. BARBOUR

The paper is printed as pages 165–172 of this volume.

BROAD VALLEYS OF THE CORDILLERAS

BY N. S. SHALER

The paper is printed as pages 271–300 of this volume.

The Society then adjourned.

Register of the Albany Meeting, 1900

The following Fellows were in attendance at the meeting:

F. D. Adams.
H. M. Ami.
Robert Bell.
A. P. Brigham.
A. H. Brooks.
M. R. Campbell.
J. M. Clarke.
A. P. Coleman.
Whitman Cross.
H. P. Cushing.
W. M. Davis.
G. M. Dawson.
J. S. Diller.
W. B. Dwight.
B. K. Emerson.
H. L. Fairchild.
A. F. Foerste.
G. K. Gilbert.
A. C. Gill.
A. W. Graham.
S. C. Glenn.
C. H. Hitchcock.
T. C. Hopkins.
E. O. Hovey.
J. P. Iddings.
J. F. Kemp.
H. B. Kümmel.
William McInnes.
F. J. H. Merrill.
G. P. Merrill.
S. L. Penfield.
R. A. F. Penrose.
W. N. Rice.
Heinrich Ries.
Charles Schuchert.
W. B. Scott.
N. S. Shaler.
G. B. Shattuck.
G. O. Smith.
J. C. Smock.
R. S. Tarr.
F. B. Taylor.
F. R. Van Horn.
A. W. Vogdes.
C. D. Walcott.
H. S. Washington.
I. C. White.
H. S. Williams.
N. H. Winchell.
J. E. Wolff.
J. B. Woodworth.

Total attendance, 51.

Session of the Cordilleran Section, Friday, December 28

The second annual meeting of the Cordilleran Section of the Society was called to order at 10.30 a m, December 28, 1900, in the council-room of the California Academy of Sciences, San Francisco.

In the absence of the Chairman, Professor Joseph Le Conte, Mr W. P. Blake* was elected temporary Chairman.

The minutes of the last meeting were read and approved.

The election of officers for the ensuing year was then taken up, with the following result:

W. C. Knight, Chairman; A. C. Lawson, Secretary; A. S. Eakle, Councillor.

These three officers are to serve as an Executive Committee for the year.

A committee consisting of Fellows Lawson, Branner, and Claypole was appointed to formulate rules and regulations for the government of the Section.

The following papers were then read:

EVIDENCES OF SHALLOW SEAS IN PALEOZOIC TIME IN SOUTHERN ARIZONA

BY WILLIAM P. BLAKE

[*Abstract*]

In the mountain ranges of southern Arizona there is abundant evidence of shallow seas and shorelines in Paleozoic time. These shores were not, perhaps, a continental margin, but rather the borders of islands, crests of submerged mountain ranges rising at intervals above the Paleozoic ocean and with a trend or direction corresponding eventually to the direction of the mountain ranges of the region.

A cross-section of the territory northeasterly from the gulf of California shows a succession of mountain ranges, some fifteen in number, in most of which ancient sandstones and conglomerates of Paleozoic age have been identified. Many of the exposures of quartzite are very thick, and these quartzites generally rest upon a coarse-grained porphyritic granite. Deep-sea deposits are not wanting. Thick beds of limestone, especially those of the Carboniferous, give evidence of depressed areas and of oscillations of level. So also the existence of thick, uplifted beds of graphitic coal in the Chiricahua mountains bear testimony to the former existence of land areas, and show a far western extension of the vegetation of the Carboniferous.

Two localities of Devonian beds were described—one in the Santa Ritas and another at the northern end of the Santa Catalina mountains.

The probable existence of Cambrian beds at several places was pointed out, and the ancient tabular gneissic rocks of the Catalinas were referred to the Archean and regarded as probable equivalents of the Huronian and Laurentian.

* Mr Blake is an ex-Fellow of the Society.

SIERRA MADRE NEAR PASADENA

BY E. W. CLAYPOLE

[*Abstract*]

The paper opened with an expression of the surprise with which geologists who have worked principally in the east witness the enormous development and the excessive diastrophism exhibited by Tertiary and even by very late Tertiary strata in the west, and these characters are as well seen in California as in any other western state. The whole Tertiary period has apparently been signalized by thick accumulation, with alternate elevation and depression. Not less has its passage been characterized by volcanic outbursts of intense energy and by quiet outflows of lava almost unequaled in massiveness and extent.

Two great mountain ranges diverging in the north and meeting again in Kern county inclose between them the San Joaquin valley. This southern meeting forms one of the great natural features of the State—the Tehachapi divide.

Speaking now only for the southern part of the state, there seems ample ground for the belief that these ranges have existed from at least Cretaceous, if not from earlier Mesozoic, time. It is not otherwise easy to find a source for the enormous Pliocene, Miocene, and Eocene accumulations of the Pacific margin so far from the Sierra Nevada.

Thick gneissic strata of two types, and standing nearly vertical, compose the range of the Sierra Madre near Pasadena. That to the south contains a large proportion of hornblende, weathers rapidly and deeply, and is consequently eroded with comparative facility. That to the north is largely feldspathic, contains little hornblende, and of it consist the white crags that stand out so boldly on the upper slopes. The former of these masses cannot be less than 2,000 to 3,000 feet thick, but it does not rise in the mountain to a greater height than 3,500 feet.

Of the wreckage from these two gneissic masses, the material filling the valley of Pasadena is composed. From great boulders near the foot of the Sierra it gradually diminishes till it becomes, in many places, a fine gravel, and at last a fine silt. This last composes the adobe land around Los Angeles, and also the many sheets of the same material which lie in the gravel, and are the holding ground of the water supply. This has been so largely exploited during the two late dry seasons that the work has resulted in restoring confidence in the water resources of the valley, of which some had become rather doubtful.

The highly aluminous nature of many of these beds indicates a very extensive decay or kaolinization of the gneisses of the Sierra and, together with the diluvial arrangement of the Pleistocene wash in the valley, rather indicates a long continuance of the present climatic conditions than a past of greater and steadier rainfall.

The multiplication of wells has not yet shown any effect in lowering the water-level, unless perhaps in a few cases, and this result is the more surprising and gratifying because it comes after two dry seasons, in which only 11 inches of rain have fallen. Already this year a greater total has been received than the above, though the wet period has scarcely begun.

When to this is added the storage of the rainwater in tanks and ponds and the reforesting of the Sierras, wherever possible, it will be seen that the maintenance of the water supply in the future is encouraging.

After considerable discussion of both papers, the Section adjourned at 12.30 p m, to meet at Berkeley in the afternoon.

At 2.30 p m the Section met in the rooms of the Geological Department of the University of California and proceeded with the reading of the papers on the program.

The following papers were then read and discussed:

DRAINAGE FEATURES OF CALIFORNIA

BY ANDREW C. LAWSON

[*Abstract*]

A comparative study of the geomorphy of the Sierra Nevada and the Coast ranges. There is a remarkable contrast in the character of the river valleys in the two mountain systems, those of the Sierra Nevada being consequent and the geomorphy immature, while those of the Coast ranges are subsequent and the geomorphy mature. In the Coast ranges the geomorphic profiles of the river valleys, leaving out of consideration the head-water streams, are not so steep as in the Sierra Nevada, and the valleys are much wider as a general rule. The divides are rounded or ridge like, with but small remnants of the earlier geomorphic cycle identifiable, in the Coast ranges, while in a large part of the Sierra Nevada the divides have a marked table or plateau form. The drainage of the Coast ranges is clearly controlled by the structure of the country, while the streams of the Sierra Nevada cut *across* the strike of the rocks and have made but little headway in the working out of canyons *along* the strike of the softer formations.

The Klamath river is regarded by the author as partly having the consequent character of the Sierra Nevada drainage and partly the character of the Coast Range drainage. The Trinity river and its prolongation in the lower Klamath belongs to the Coast Range system, being parallel to the strike of the country and in part mature in its development, while the upper Klamath is consequent and young. This affords us a basis for the separation of the Klamath mountains from the Coast ranges, and supports the orogenic correlation of the Klamath mountains with the Sierra Nevada. The comparison thus made points clearly to the conclusion that the Sierra Nevada and probably also the Klamath mountains are of later date than the emergence of the Coast ranges which inaugurated the present cycle of geomorphic evolution. But the subsequent valleys of the Coast ranges are in several instances known to have been evolved after the deformation of the Pliocene, and we are thus forced to place a very late geological date upon the tilting of the Sierra Nevada orographic block.

DESCRIPTION OF BATES HOLE, WYOMING *

BY WILBUR C. KNIGHT

[*Abstract*]

Bates hole, a great natural depression, is located along the east and west boundary line between Carbon and Natrona counties, Wyoming, extending southward

* Illustrated with lantern slides.

from 6 to 10 miles into Carbon county and from 20 to 25 miles into Natrona county. The bottom of this depression is 800 feet below the rim near the head and over 1,700 feet below it near the Platte river. The drainage is practically confined to Camp creek, which rises at the southern end of the hole, but which affords water for only a portion of the year, and Bates creek, which rises in the Laramie mountains and furnishes quite a stream. The country about this area is comparatively level, but to the eastward only a few miles rise the Laramie mountains, and to the westward the Indian grove and other ranges, which are made up of Mesozoic, Paleozoic, and Archean rocks. In length Bates hole varies from 25 to 35 miles, and in width from 6 to 12 miles, the lower end being much the wider. The dominant formation entering into the structure of this region is Tertiary, but this rests nearly horizontally on a very uneven floor of older rocks, which in the central portion have been exposed and suffered extensive erosion. From the rim the slopes are very steep throughout, seldom being less than 15 to 20 degrees and usually much higher, and in many instances from 28 to 34 degrees. Occasionally there are vertical walls of the Tertiary rocks from 100 to 200 feet, carved in the most unusual manner and often cut with deep, narrow, dry gorges. Capping the highest Tertiary escarpments there is a heavy conglomerate of unknown age. Beneath this are the Titanotherium beds, which have a thickness of about 600 feet, and in local depressions in the Cretaceous series underlying this region there is a third series of Tertiary beds, composed of variegated clays and sands, that is in all probability Eocene. Along the Platte river all of the Tertiary rocks have been removed, and along the Laramie mountains there are exposed in natural order Cretaceous, Jurassic, Triassic, Carboniferous, Cambrian, and Archean as one ascends the range. Along the Tertiary escarpments are numerous stunted pines (*Pinus flexlis*) whose roots are exposed from 1 to 8 feet, which signifies very rapid erosion. This erosion has been very general, and data which will aid us in determining the age of Bates hole are well in hand.

*GEOLOGICAL SECTION THROUGH JOHN DAY BASIN**

BY J. C. MERRIAM

[*Abstract*]

The John Day river and its tributaries have exposed in the erosion of their canyons about 10,000 feet of strata, giving a full series of formations from Lower Cretaceous to Quaternary.

The oldest rocks in this region which are known to the writer are a series of altered sedimentaries in the northeastern part of the basin. They are pretty certainly of pre-Cretaceous age and are underlain by quartz diorite,† which is presumably intruded into them.

On Bridge creek, near Mitchell, a great thickness of Cretaceous is exposed. The lower 2,000 to 3,000 feet of this section are typical Knoxville. The upper 1,000 to 2,000 feet are Chico.

Resting upon the Chico, near Mitchell, also showing typical exposures at Clarnos ferry, is a presumably Eocene formation, to which the name Clarno is given. This

* The paper was illustrated with lantern slides showing the principal formations and their relations to each other.

† Determined by Frank C. Calkins.

formation is made up entirely of tuffs, ashes, and lavas. In places it contains many plant remains and is apparently in part a fresh-water formation.

The John Day formation rests directly upon the Clarno at Clarnos ferry. The basin in which it was deposited is quite different from that of the Clarno. It probably rests unconformably upon that formation. The Lower John Day beds are considerably contorted in some localities. Ordinarily they are colored a deep red. Fossil remains are exceedingly rare in this division.

The blue-green beds of the Middle John Day are very fossiliferous. They correspond to the Diceratherium beds of Wortman. The Upper or Buff beds of the John Day lap over the middle division and rest in places upon the older formations. The upper division corresponds to the Merycochœrus beds of Wortman. As *Merycochœrus* does not occur in the John Day, the upper division will be called the Paracotylops beds. This name is based on the new generic name proposed by W. D. Matthew for the Upper John Day oreodons, originally supposed to be *Merycochœrus*.

The Columbia lava, an extension of the lavas on the Columbia river to the north, rests unconformably on the crumpled John Day formation. The name Columbia lava should be restricted to this horizon of the lavas in this region, as other beds included in this group belong in some cases to different geological periods.

The Cottonwood (Loup Fork) formation, near 1,000 feet in thickness, rests on the Columbia lava. The Van Horn Ranch plants, which have generally been considered as John Day, are from this horizon. Remains of a true John Day flora, which had not previously been known, were discovered by the University of California expedition in 1900. The discovery of the true stratigraphic position of the Van Horn Ranch flora explains the apparent inverted position of the Neocene formations in central Washington.

Resting on the worn edges of the Cottonwood beds is the Rattlesnake formation, comprising several hundred feet of gravel, tuff, and lava.

In canyons cut through the Rattlesnake and Cottonwood are several terraces. Remains of elephants and later horses found in the lower terrace deposits show that they were formed in Quaternary time.

The Section then adjourned to meet at the same place at 10 o'clock the following morning, the exhibition of slides illustrating Doctor Merriam's paper being postponed till that time.

SESSION OF THE CORDILLERAN SECTION SATURDAY, DECEMBER 29

The Section met at 10 a m in the rooms of the Geological Department of the University of California, the chairman-elect, Professor Knight, in the chair.

Dr J. C. Merriam exhibited the lantern slides illustrating his paper.

The following papers were then read and discussed:

*GEOLOGY OF THE GREAT BASIN IN CALIFORNIA AND NEVADA**

BY H. W. TURNER

[*Abstract*]

The ridges of the western edge of the Great Basin in Nevada and eastern California are usually very complex in structure and composition. They comprise sediments of Paleozoic and Jura-Trias age, much disturbed at some points by intrusions of granolites. In Tertiary time there were extensive lakes, and contemporaneous with these lakes, and also later, are lavas and tuffs in large amounts, chiefly rhyolites, andesites, and basalts.

Structurally, the region is characterized by ranges upheaved along normal faults, but in places previously folded. A portion of the Silver Peak range is composed of a series of granites, gneisses, and schists which are pre-Cambrian in age and presumably Archean. The sedimentary rocks range from the oldest Cambrian to Recent, but no rocks of Cretaceous age are known to be present. The Paleozoic and older Mesozoic terranes are intruded by a great variety of granolites. There is some serpentine that appears to have formed from diopside, that mineral possibly being derived from the metamorphism of magnesian limestone.

The formation of the ranges, or at least their latest uplifts, dates from the late Tertiary and post-Tertiary time.

They were elevated along normal faults, the valleys being in part subsided areas, often of the nature of rock basins, whose rims are composed of rocks older than the desert detritus.

There are some gneisses pretty certainly of pre-Cambrian age. These gneisses underlie Lower Cambrian sediments rich in fossil remains at some points. There is an extensive chert series containing abundant graptolites supposed to be of Lower Silurian age. There are Lower Trias beds in the Inyo range and Jurassic limestone in the Pilot mountains.

The lavas consist of a Paleozoic series comprising meta-rhyolites, keratophyres, and meta-dacites and a Tertiary series of rhyolites, latites, dacites, andesites, and basalts, the succession taken in a large way being about in the order named. There are, however, rhyolites and andesites of different ages, and one type of dacite is among the oldest of the Tertiary lavas.

The supposed Archean rocks contain gold-silver quartz veins of great value.

A series of Tertiary lake beds contain beds of coal and abundant plant, molluscan, and fish remains and the playas of the valleys rich deposits of chloride of sodium and borax.

GEOLOGY OF THE THREE SISTERS, OREGON

BY H. W. FAIRBANKS

[*Abstract*]

The Three Sisters form a group of volcanic peaks on the summit of the Cascade range in central Oregon. They rise to a height of about 10,000 feet, and are quite similar in many respects to the other great volcanic peaks which mark the crest of the Cascade range through Oregon and Washington.

* The paper was illustrated with lantern slides.

This group of peaks is marked by the presence of a glacier nearly three miles long and a half a mile wide.

To the north of the peaks recent volcanic activity is indicated by extensive flows of basic lavas. Volcanic eruptions have occurred since the Glacial period, as shown by the relation of the lavas to the grooved and polished surfaces. A volcanic cone on the North Sister lies in the path of the present glacier.

Petrographically the region is also an interesting one.

At 12.30 p m the Section adjourned for luncheon.

After luncheon the following papers were read and discussed:

SKETCH OF THE PEDOLOGICAL GEOLOGY OF CALIFORNIA

BY E. W. HILGARD

[*Abstract*]

Owing to the great climatic diversity, the rainfall varying from 2 inches at the south to as much as 80 inches in the north, even a sketch of the soil conditions of California must take the climates into consideration. The cardinal difference between rock decomposition in arid as compared with humid climates lies in the retardation of kaolinization, as exemplified in the monoliths of Egypt and the granites of the Sierra Madre, as compared, for example, with the Alleghanies. Hence in northern California and on the higher Sierra Nevada we find loams and clay soils, while at the lower levels and in southern California the soils are "dusty" or sandy, except where derived from preexisting clay formations, which give rise to "adobe," and in the upper valleys of the rivers of the Sierra, which carry the materials from the higher levels.

Throughout the middle and southern parts of the State, where no rains of consequence fall between May and November, not only is the soil mass usually of extraordinary depth, but is scarcely changed for several, sometimes for 4 to 10, feet. There is practically no subsoil, in the usual sense, in the absence of clay; water, roots, and air penetrate together to depths impossible in the regions of summer rains, and hence the extraordinary endurance of drought, even by plants foreign to the arid region. Moreover, these soils almost universally contain high percentages of lime and potash, due to the absence of the leaching process, which, on the other hand, results in the formation of "alkali soils"—too complex a subject to be dealt with here.

"Sand" in the arid soils is not merely quartz grains, but consists of all the original minerals, superficially decomposed. Hence sandy lands are here fully as rich as clay lands are elsewhere.

In the Great valley it is easy to recognize by their microscopic characters the alluvial areas of the several rivers coming in from the Sierra. Even here the greater rainfall of the Sacramento is evidenced by loam and clay lands, as compared with the San Joaquin valley, where sandy and silty lands prevail altogether. As the rainfall decreases toward the Coast ranges, the "lightest" are found under the arid lee on the west border of the valley. In its axis, in the "tule lands," as well as on the borders of the bays near its outlet, heavy clay soils are being formed in the slack water, while the streams coming from the Coast ranges are bordered

by light, silty lands, the "truck lands" from which San Francisco markets are supplied. Along the foothills of the Sierra there lies a belt, of varying width, of heavy red clay lands, probably derived from Ione formation and frequently closely packed with gravel. These materials are intrinsically poor in plant food, and, being difficultly penetrable by roots, have caused much disappointment to settlers, and were the first to be treated by the energetic method of blasting with dynamite for fruit culture. They improve materially toward the south, and in Fresno county form the basis for successful citrus culture. Higher up in the foothills come the characteristic red soils, the gold-bearing earths, mostly derived from the older slates and sedentary thereon. They are interspersed with patches of gray "granite" lands, which are very much less productive, being derived from the granodiorites, deficient in potash and phosphoric acid.

The soils of the Coast ranges vary greatly, with their varying rock formations, among which are much clay and clay shale, forming correspondingly heavy soils; but the valleys also are filled with deep silty or sandy deposits. Southward the Coast ranges are continued in the Sierra Madre, which forms the northern wall of the valley of southern California.

This valley, now subdivided into the drainage basins of the Santa Ana and San Gabriel, was undoubtedly originally a unit. This is proved by a terrace of "red lands," which extends all around from Redlands and Riverside to Los Angeles. Its subdivision was effected in late times by the great debris cone of the San Antonio creek, which, abutting against the Puente hills, cuts the drainage in two. The red soils are the special ones for citrus culture, but the sandy and silty alluvium of the two rivers also serves the same purpose.

NEOCENE BASINS OF THE KLAMATH MOUNTAINS

BY F. M. ANDERSON *

[*Abstract*]

This paper is an attempt to show some of the more salient structural features of the Klamath mountains, including not only their basins, but also their principal ranges. The three chief ranges of the group, extending in a northeasterly direction from the coast, and the drainage basins intervening and otherwise associated form the main subject of discussion. Of the two systems of ranges crossing each other nearly at right angles, the northeast and southwest ranges are the older and have exerted a controlling influence over the drainage since their beginning. The principal rivers of the region—the Rogue river, the Klamath, and the Trinity—cut transversely across the more nearly north and south ranges, showing them to be younger in age than the lines of drainage followed by these streams, and accordingly younger in age than the east and west ranges.

The historical development of these drainage basins is shown by the deposits contained in them, and for some of them it antedates the later Cretaceous epochs at least. The earliest drainage of the basin of the Klamath lakes is shown to have been through the valley of Rogue river, and to have been diverted from that course to its present by some of the later lava flows from the Cascades. Evidence is cited to show that during the Chico epoch this basin was not connected with that of the

* Presented by A. C. Lawson.

Pitt river or the Sacramento, and it is maintained that its individuality has been kept almost unchanged to the present. As one of the larger streams of the region, therefore, the Klamath is younger in age than either the Trinity or the Rogue river.

AGE OF CERTAIN GRANITES IN THE KLAMATH MOUNTAINS

BY OSCAR H. HERSHEY *

[*Abstract*]

Small batholites and dikes of granite, quartz-mica-diorite, and intermediate types are shown to occur at various places in the Klamath region, but in areas quite subordinate in extent to those of the metamorphic rocks into which they have been intruded. The same contains extensive areas of serpentine, and instances are given of the granitic rocks having been intruded into the serpentine to prove that the granites are newer, in accordance with the determined relations of these rock-types in the Sierra Nevada region, and the reverse of the supposed relation between the granite and the serpentine of the Coast ranges.

The black slates of the Klamath region are divided into two distinct series, referred to as the Lower slates and the Upper slates. The former are considered Devono-Carboniferous in age, being in part equivalent to the Calaveras formation. The latter are correlated, on the evidence of their lithology and of their structural relations to the Lower slates and to a certain extrusive greenstone formation similar to the diabase and porphyritic formation of the Sierra Nevada region, with the Mariposa formation of late Jurassic age. The intrusion of granite occurred later than the deposition of these Upper slates; also it is shown that the granites are much older than the Chico formation resting on them, as they had suffered much erosion prior to the Chico epoch.

It is finally concluded that the weight of evidence places the granitic intrusion just about at the close of the Jurassic period. The effect of the argument is to show that there is a sound basis for the inference heretofore entertained that the Klamath mountains belong rather to the Sierra Nevada system than to the Coast ranges and may be considered a sort of outlier to the former.

FELDSPAR-CORUNDUM ROCK FROM PLUMAS COUNTY, CALIFORNIA

BY ANDREW C. LAWSON

[*Abstract*]

Mr Turner, of the United States Geological Survey, has called attention to the prevalence of feldspathic "albitic" dikes cutting serpentine in various parts of the Sierra Nevada. The rock of which the present paper treats apparently belongs to this series of dikes. It occurs as a white, coarse grained dike cutting the serpentine of the eastern flank of Spanish peak, Plumas county. The rock is composed of 84 per cent of oligoclase and 16 per cent of corundum in crystals up to over 2 inches in length, and rather irregularly distributed through the feldspathic groundmass.

The following is an analysis of the feldspar:

SiO_2, 61.36; Al_2O_3, 22.97; Na_2O, 8.08; CaO, 5.38; H_2O, 1.72. Total, 99.51; Sp. gr., 2.63.

* Presented by A. C. Lawson.

The occurrence is of special interest as one of the rare cases of a rock supersaturated with alumina, and its occurrence as a dike in a rock devoid of alumina, soda, and lime is of especial interest as supporting a case of extreme differentiation of rock magma.

The Section then adjourned.

ANDREW C. LAWSON, *Secretary.*

REGISTER OF MEETING OF THE CORDILLERAN SECTION, 1900

The following Fellows were in attendance at the meeting:

E. W. CLAYPOLE.
A. S. EAKLE.
H. W. FAIRBANKS.
E. W. HILGARD.
W. C. KNIGHT.
A. C. LAWSON.
J. C. MERRIAM.
H. W. TURNER.

The visitors were

F. M. ANDERSON.
W. P. BLAKE.
W. C. BLASDALE.
F. C. CALKINS.
H. W. FURLONG.
O. H. HERSHEY.
G. D. LOUDERBACK.
DR NEWCOMB.
J. W. SINCLAIR.

ACCESSIONS TO LIBRARY FROM JUNE, 1900, TO JUNE, 1901

By H. P. Cushing, *Librarian*

Contents

(*A*) From Societies and Institutions receiving the Bulletin as Donation ("Exchanges")

(*a*) *AMERICA*

NEW YORK STATE MUSEUM, ALBANY

1266. Annual Report no. 49, part 3, 1895.
1530. " " " 50, part 2, 1896.
1945. " " " 51, part 1, 1897.
1945. " " " 51, part 2, 1897.
1978-1979. " " " 52, parts 1 and 2, 1898.

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

1700. Proceedings, vol. xxix, nos. 12-16, 1899-1900.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

1539. Comunicaciones, tomo 1, núm. 6-7, 1900.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

1913. Bulletin of Natural History Survey, no. iv, part i, 1900.
834. Bulletin, vol. ii, no. 3, 1900.

FIELD COLUMBIAN MUSEUM, CHICAGO

1000. Publication 53, Geological Series, vol. i, no. 8, 1901.
1030. " 49, Zoological Series, vol. i, no. 18, 1900.
1031. " 52, Report Series, vol. i, no. 6, 1900.
1916. " 46, 47, 54, Zoological Series, vol. iii, nos. 1-3.
1988. " 53, Zoological Series, vol. ii, 1901.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

1034. Journal, vol. xix, nos. 6–8, 1900.

COLORADO SCIENTIFIC SOCIETY, DENVER

1990. Proceedings, vol. vii, pp. 1–36, 1901.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

1771. Proceedings and Transactions, vol. x, part 2, 1900.

MUSEO DE LA PLATA, LA PLATA

1963. Anales, Seccion geologica et mineralogica, II, 1900.

INSTITUTO GEOLOGICO DE MEXICO, MEXICO

1981. Boletin, núm. 14, La Rhyolitas de Mexico, part i, 1900.

NATURAL HISTORY SOCIETY, MONTREAL

255. Canadian Record of Science, vol. v, nos. 5-7, 1895.
1040. " " " " " vii, nos. 3, 5, 6, 8, 1897.
1946. " " " " " viii, nos. 1–5.

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

1654. Bulletin, vol. xxxi, nos. 4–5, 1899.
1991. " " xxxii, nos. 1–5, 1900.
1992. " " xxxiii, no. 1, 1901.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

1507. Bulletin, vol. xi, part iii, 1900.
1975. " " xiii, 1900.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

1687. Annals, vol. xii, parts 2–3, 1899.
1948. " " xiii, parts 1–3, 1900.
1769. Memoirs, vol. ii, part 2, 1900, 4to.

GEOLOGICAL SURVEY OF CANADA, OTTAWA

1980. Relief Map of Canada and the United States.

ROYAL SOCIETY OF CANADA, OTTAWA

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

1813. Proceedings, vol. lii, parts 1–3, 1900.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

1776. Proceedings, vol. xxxix, nos. 162–164, 1900.

MUSEO NACIONAL DE RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

1282. Proceedings, third series, Geology, vol. i, nos. 7–9, 1900.

GEOLOGICAL SURVEY OF NEWFOUNDLAND, ST. JOHNS

ACADEMY OF SCIENCE, ST. LOUIS

1775. Transactions, vol. x, nos. 3–11, 1900.
2009. " " xi, no. 1, 1901.

COMMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

NATIONAL GEOGRAPHIC SOCIETY, WASHINGTON

1750. National Geographic Magazine, vol. xi, nos. 6–12, 1900.
1964. " " " " xii, nos. 1–5, 1901.

LIBRARY OF CONGRESS, WASHINGTON

SMITHSONIAN INSTITUTION, WASHINGTON

1965. Annual Report, 1898.

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

1949–1954. Twentieth Annual Report, parts 2–5, 5 atlas, and 7, 1900.
1955. Preliminary Report on the Cape Nome Region, Alaska, 1900.
1956. Map of Alaska, etc., 1898.
1968. Monograph xxxix.
1969–1970. Bulletins, nos. 163–174.
1971. Bulletins, nos. 175, 176.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

(b) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

1731. Zeitschrift, band li, heft 4, 1899.
1917. " " lii, heft 1–3, 1900.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

1972–1974. Jahrbuch, band xvii–xix, 1896–'98.

GEOGRAPHISCHEN GESELLSCHAFT, BERNE

2005. Jahresbericht, xvii, 1898–'99.

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

1927–1928. Rendiconto, nuova serie, vols. ii–iii, 1897–'99.
1929. Memorie, serie v, tomo vii, 1897–'99.

ACADÉMIE ROYALE DE BELGIQUE, BRUSSELS

1958. Bulletin de la Classe des Sciences, 1899.

SOCIÉTÉ BELGE DE GÉOLOGIE, DE PALÉONTOLOGIE ET D'HYDROLOGIE, BRUSSELS

1444. Bulletin, tome xi, fasc. 4, 1897.
1911. " " xiii, fasc. 1, 2, 1899.
1912. " " xiv, fasc. 1–4, 1900.
2006. " " xv, fasc. 1, 1901.

BIUROULI GEOLOGICA, BUCHAREST

MAGYARHONI FÖLDTANI TARSULAT, BUDAPEST

886. Földtani Közlöny, xxv kötet, 6-10 fuset, 1895.
1118. " " xxvi kötet, 5-6 fuset, 1896.
1749. " " xxix kötet, 8-12 fuset, 1899.
1940. " " xxx kötet, 1-9 fuset, 1900.
1943. Die Tertiarbildungen des Beckens der Siebenburgischen Landestheile, ii Abtheilung, von Doctor Anton Koch.

NORGES GEOLOGISKE UNDERSOGELSE, CHRISTIANA

DANMARKS GEOLOGISKE UNDERSOGELSE, COPENHAGEN

1755. Beskrivelse til Geologisk Kort over Danmark, Raekkei, nr. 7, 8.

ACADÉMIE ROYALE DES SCIENCES ET DES LETTRES DE DANEMARK, COPENHAGEN

1780. Oversigt i Aaret, 1900, Nr. 2-6.
2003. " " 1901, Nr. 1.

NATURWISSENSCHAFTLICHEN GESELLSCHAFT ISIS, DRESDEN

1918. Sitzungsberichte und Abhandlungen, Jahrgang 1900.

ROYAL SOCIETY OF EDINBURGH, EDINBURGH

1489. Transactions, vol. xxxix, part 2, 1900, 4to.
1925. " " xxxix, parts 3, 4, 1900, 4to.
1926. Proceedings, vol. xxii, 1897-'99, 8vo.

NATURFORSCHENDEN GESELLSCHAFT, FREIBURG I. B

1707. Berichte, band xi, heft 2, 1900.

ROYAL SOCIETY OF GLASGOW, GLASGOW

PETERMANN'S GEOGRAPHISCHE MITTHEILUNGEN, GOTHA

KSL. LEOP. CAROL. DEUTSCHEN AKADEMIE DER NATURFORSCHER, HALLE

1995-1996. Nova Acta, Abhandlungen, band 75, 76, 1900.
1997. Leopoldina, heft xxxv, 1899.

GEOLOGISKA UNDERSOKNING, HELSINGFORS

1126. Beskrifning till Kartbladet, no. 35, 1900, with maps.
1516. Bulletin no. xi, 1900.

SOCIÉTÉ DE GÉOGRAPHIE DE FINLANDE, HELSINGFORS

SOCIÉTÉ GÉOLOGIQUE SUISSE, LAUSANNE

GEOLOGISCH REICHS-MUSEUM, LEIDEN

1710. Beiträge zur Geologie Ost-Asiens und Australiens, band vi, heft ii, 1900.

KÖNIGLICH-SÄCHISCHE GESELLSCHAFT DER WISSENSCHAFTEN, LEIPSIC

1774. Berichte über die Verhandlungen, Math.-Phys. Klasse, 1900, heft 2, 3, 5-7.
1768. Abhandlungen der Math.-Phys. Classe, band xxvi, heft 3, 4.

SOCIÉTÉ GÉOLOGIQUE DE BELGIQUE, LIEGE

1696. Annales, tome xxvi, livr. 4, 1900.
1767. " " xxvii, livr. 2-4, 1900.
2008. " " xxviii, livr. 1, 1901.
2007. " " xxv bis, livr. 1, 4to.

SOCIÉTÉ GÉOLOGIQUE DU NORD, LILLE

1939. Annales, tome xxviii, 1899.

COMMISSAO DOS TRABALHOS GEOLOGICOS DE PORTUGAL, LISBON

1819. Carta Geologica de Portugal, 1900.

BRITISH MUSEUM (NATURAL HISTORY), LONDON

1923. Monograph of Christmas Island, 1900.
1924. Catalogue of Cretaceous Bryozoa, part 1, 1900.
1989. The Jurassic Flora, Yorkshire, part 1, 1900.

GEOLOGICAL SOCIETY, LONDON

1763. Quarterly Journal, vol. lvi, parts 2-4, nos. 222-224, 1900.
1350. List of the Geological Society of London, December, 1900.
1976. Quarterly Journal, vol. lvii, parts 1-2, nos. 225-226, 1901.

GEOLOGICAL SURVEY, LONDON

GEOLOGISTS' ASSOCIATION, LONDON

1659. Proceedings, vol. xvi, parts 7-10, 1899-1900.
2002. " " xvii, part 1, 1901-'02.

COMISION DEL MAPA GEOLOGICA DE ESPANA, MADRID

SOCIETÀ ITALIANA DI SCIENZE NATURALI, MILAN

1906. Atti, vol. xxxix, fasc. 1-4, 1900.

SOCIÉTÉ IMPERIALE DES NATURALISTES DE MOSCOU, MOSCOW

1677. Bulletin, Année 1898, nos. 2-4.
1902. " " 1899, nos. 1-4.
1999. " " 1900, nos. 1-2.

K. BAYERISCHE AKADEMIE DER WISSENSCHAFTEN, MUNICH

1747. Sitzungsberichte der Math.-Phys. Classe, 1899, heft 3.
1965. " " " " " 1900, heft 1-2.
1572. Rede und Festrede, 3 separates, 1899-1900.

RADCLIFFE LIBRARY, OXFORD UNIVERSITY MUSEUM, OXFORD

ANNALES DES MINES, PARIS

1764. Annales, tome xvii, livr. 4-6, 1900.
1938. " " xviii, livr. 7-12, 1900.
1985. " " xix, livr. 1, 1901.

CARTE GÉOLOGIQUE DE LA FRANCE, PARIS

SOCIÉTÉ GÉOLOGIQUE DE FRANCE, PARIS

1907. Bulletin, 3d Serie, tome xxviii, nos. 1-7, 1900.

REALE COMITATO GEOLOGICO D'ITALIA, ROME

1908. Bolletino, vol. xxxi, nos. 1-4, 1900.

SOCIETÀ GEOLOGICO ITALIANA, ROME

1914. Bolletino, Anno xviii, fasc. 1-3, 1899.
2004. " " xix. fasc. 1-3, 1900.
409. " " x, fasc. 1, 1891.

ACADÉMIE IMPERIALE DES SCIENCES, ST. PETERSBURG

1536. Bulletin, v^e serie, tome ix, nos. 2-4, 1898.
1932. " " " x, nos. 1-5, 1899.
1933. " " " xi, nos. 1-5, 1899.
1934. " " " xii, nos. 1-5, 1900.
1935. Memoirs, viii^e serie, tome vi, no. 2.
1936. " " " viii, nos. 1, 2, 7, 10.
1937. " " " ix, no. 1, 1899.
1993. Bulletin, v^e serie, tome xiii, nos. 1-3, 1900.

COMITÈ GÉOLOGIQUE DE LA RUSSIE, ST. PETERSBURG

1537. Bulletin, vol. xvii, nos. 6-10, 1898.
1901. " " xviii, nos. 1-10, 1899-1900.
379. Memoirs, vol. viii, nos. 1, 3, 4.
383. " " xii, no. 3, 1899.
377. " " iv, no. 1, 1886.
1173. " " xv, no. 3, 1899.
380. " " ix, nos. 1, 5, 1888, 1899.
1938. " " vii, nos. 1, 4, 1888, 1899.

RÜSSICH-KAISERLICHEN MINERALOGISCHEN GESELLSCHAFT, ST. PETERSBURG

1903. Verhandlungen, Zweite Serie, band xxxvi, lief. 1-2, 1898.
1905. " " " xxxvii, lief. 1-2, 1899.
2000. " " " xxxviii, lief. 1, 1900.
1904. Materialen zur Geologie Russlands, band xix.
1998. " " " " " xx.

GEOLOGISKA BYRAN, STOCKHOLM

GEOLOGISKA FÖRENINGENS, STOCKHOLM

1760. Förhandlingar, band xxii, häfte 5-7, nos. 201-203, 1900.
1977. " " xxiii, häfte 1-3, nos. 204-206, 1901.

NEUES JAHRBUCH FÜR MINERALOGIE, GEOLOGIE UND PALEONTOLOGIE, STUTTGART

1762. Jahrgang, 1900, band i. heft 2-3.
1919. Centralblatt, 1900, nos. 1-12.

1920. Jahrgang, 1900, band ii, heft 1-3.
1966. " 1901, band i, heft 1.
1987. Centralblatt, 1901, nos. 1-2.

KAISERLICH-KÖNIGLICHEN GEOLOGISCHEN REICHANSTALT, VIENNA

1733. Jahrbuch, band xlix, heft 4, 1899.

KAISERLICH-KÖNIGLICHEN NATURHISTORISCHEN HOFMUSEUMS, VIENNA

1941. Annalen, band xiv, nr. 1-4, 1899.
1942. " " xv, nr. 1, 1900.

DIE BIBLIOTHEK DES EIDG. POLYTECHNICUMS, ZURICH

(*c*) *ASIA*

GEOLOGICAL SURVEY OF INDIA, CALCUTTA

1517. General Report of the Work, April 1, 1899, to March 31, 1900.
1930. Memoirs, vol. xxix, 1900.
1931. " " xxx, part 1, 1900.
1706. " " xxviii, part 2, 1900.
2001. " " xxxiii, part 1, 1901.

IMPERIAL GEOLOGICAL SURVEY, TOKYO

(*d*) *AUSTRALASIA*

GEOLOGICAL DEPARTMENT OF SOUTH AUSTRALIA, ADELAIDE

1515. Record of the Mines, Report on Gold Discovery at Tarcoola, etc.
1957. Geological Map of South Australia, 4 sheets, 1900.

GEOLOGICAL SURVEY OF QUEENSLAND, BRISBANE

CANTERBURY MUSEUM, CHRISTCHURCH

DEPARTMENT OF MINES OF VICTORIA, MELBOURNE

1713. Annual Report of the Secretary for 1899.
1735. Monthly Progress Reports, nos. 8-9, 1899.
1915. " " " " 10-12, 1900.
1961. Report on the Utilization of Brown Coal on the Spot where it is Mined, etc., 1900.
1962. Report on the Queen, Moliagul, and other Mines, Moliagul.
1963. Report on the Mount William Gold Field.
1582. Annual Progress Report for the Year 1899.

GEOLOGICAL DEPARTMENT OF WESTERN AUSTRALIA, PERTH

1909. Geological Map of the Country between Cue Peak Hill and Menzies.
1910. Geological Map of Menzies, G. F.
1499. Bulletin, nos. 4, 5.

GEOLOGICAL SURVEY OF NEW SOUTH WALES, SYDNEY

1478. Mineral Resources, no. 7, 1900.
Records, vol. vi, part 4, 1900.

1982. Memoirs, Geology, no. 1, Vegetable Creek Tin Mining Field.
1983. " Paleontology, no. 4, Fossil Fishes of the Hawkesbury Limestone, 1890.
1984. Memoirs, Paleontology, no. 7, Mesozoic and Tertiary Insects of New South Wales, 1890.

ROYAL SOCIETY OF NEW SOUTH WALES, SYDNEY

1944. Journal and Proceedings, vol. xxxiii, 1899.

(*e*) *AFRICA*

GEOLOGICAL COMMISSION, CAPE TOWN

(*f*) *HAWAIIAN ISLANDS*

HAWAIIAN GOVERNMENT SURVEY, HONOLULU

(*B*) From State Geological Surveys and Mining Bureaus

UNIVERSITY GEOLOGICAL SURVEY OF KANSAS, LAWRENCE

2011. Mineral Resources of Kansas, 1899.

GEOLOGICAL AND NATURAL HISTORY SURVEY OF MINNESOTA, MINNEAPOLIS

1947. Final Report, vol. v, 1900.

CALIFORNIA STATE MINING BUREAU, SAN FRANCISCO

2012. Bulletin no. 18, Mother Lode Region of California.

GEOLOGICAL SURVEY OF NEW JERSEY, TRENTON

1959. Annual Report of the State Geologist for 1899.
1960. Report of Forests, with Maps, 1899.

GEOLOGICAL SURVEY OF ALABAMA, UNIVERSITY

2013. Report on the Warrior Coal Basin.
2014. Bulletin no. 6, Preliminary Report on the Clays of Alabama.

(*C*) From Scientific Societies and Institutions

GEOLOGISCHEN KOMMISSION DER SCHWEIZ.-NATURFORSCHENDEN GESELLSCHAFT, BERNE

1921. Beiträge zum Geologischen Karte der Schweiz, neue Folge, lief. ix, 1900.
1994. Same, lief. x, 1900.

SCHLESISCHE GESELLSCHAFT FÜR VATERLÄNDISCHE CULTUR, BRESLAU

2015. Siebenundsiebzigster Jahres-bericht, 1899.
1602. Litteratur der Landes-und Volkskunde der Provinz Schlesien, heft 7, 1900.

SOCIEDAD CIENTIFICA "ANTONIO ALZATE," MEXICO

1752. Memorias y Revista, tomo xiv, Núms. 5–12, 1899–1900.
1986. " " " xv, Núms. 1-6, 1900–1901.

NATURFORSCHER-VEREINS ZU RIGA, RIGA

2016. Korrespondenzblatt xliii, 1900.
2017. Arbeiten heft x, Die Baltischen Wirbelthere, G. Schweder.

TOKYO GEOGRAPHICAL SOCIETY, TOKYO

2018. Journal of Geography, vol. xii, nos. 134–138, February–June, 1900.

(*D*) FROM FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA (PERSONAL PUBLICATIONS)

HENRY M. AMI

2019. Biographical Sketch of Sir William Dawson.

PERSIFOR FRAZER

2020. The Life and Letters of Edward Drinker Cope.

ULYSSES SHERMAN GRANT

2021. Preliminary Report on the Copper-bearing Rocks of Douglas County, Wisconsin.

C. L. HERRICK

2028. The Geology of the San Pedro and the Albuquerque Districts, New Mexico.

C. H. HITCHCOCK

2022. Volcanic Phenomena on Hawaii.
2023-2024. Two separate papers.

GEORGE P. MERRILL

2025. Guide to the Study of the Collections in the Section of Applied Geology; the Non-metallic Minerals, U. S. National Museum.

EZEQUIEL ORDOÑEZ

2026. Les Volcans du Valle de Santiago.
2027. Un Voyage a la "Sierra Madre del Sur."

CHARLES D. WALCOTT

2029. The Work of the United States Geological Survey in Relation to the Mineral Resources of the United States.

HENRY S. WASHINGTON

2030. A Chemical Study of the Glaucophane Schists.
2031. The Composition of Kulaite.
2032. The Statement of Rock Analyses.
2033. Igneous Complex of Magnet Cove, Arkansas.

(*E*) FROM MISCELLANEOUS SOURCES

ARTHUR CHAMBERLAIN, EDITOR

2034. The Mineral Collector, vol. vii, no. 5.

CINCINNATI MUSEUM ASSOCIATION, CINCINNATI

2035. Nineteenth Annual Report, 1899.

REVUE CRITIQUE DE PALÉOZOOLOGIE PARIS

2036. Quatrième Année, Numéro 2, Avril, 1900.

C. G. HEREUS (1720)

2037. La Caverne de Ratelstein en Styrie.

GRORGES CARRÉ ET C. NAUD, EDITEURS

2038.. La Spéléologie, par E. A. Martel.

G. RAMOND

2039. Études Géologiques dans Paris et sa Banlieue.
2040. Observations Géologiques, etc.
2041. Étude Géologique de l'Aqueduc du Loing et du Lunain.
2042. La Geographie Physique et la Géologie a l'Exposition Universelle de 1900.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1901

President

C. D. WALCOTT, Washington, D. C.

Vice-Presidents

N. H. WINCHELL, Minneapolis, Minn.

S. F. EMMONS, Washington, D. C.

Secretary

H. L. FAIRCHILD, Rochester, N. Y.

Treasurer

I. C. WHITE, Morgantown, W. Va.

Editor

J. STANLEY-BROWN, Washington, D. C.

Librarian

H. P. CUSHING, Cleveland, Ohio.

Councillors

(Term expires 1901)

W. M. DAVIS, Cambridge, Mass.

J. A. HOLMES, Chapel Hill, N. C.

(Term expires 1902)

W. B. CLARK, Baltimore, Md.

A. C. LAWSON, Berkeley, Cal.

(Term expires 1903)

SAMUEL CALVIN, Iowa City, Iowa.

A. P. COLEMAN, Toronto, Canada.

FELLOWS, NOVEMBER 8, 1901

* Indicates Original Fellow (see article III of Constitution)

CLEVELAND ABBE, JR., Ph. D., 2017 I St. N. W., Washington, D. C. August, 1899.

FRANK DAWSON ADAMS, Ph. D., Montreal Canada; Professor of Geology in McGill University. December, 1889.

JOSÉ GUADALUPE AGUILERA, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

TRUMAN H. ALDRICH, M. E., Birmingham, Ala. May, 1889.

HENRY M. AMI, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

PHILIP ARGALL, 821 Equitable Building, Denver, Colo.; Mining Eng. August, 1896.

GEORGE HALL ASHLEY, M. E., Ph. D., Charleston, S. C.; Professor of Natural History, College of Charleston. August, 1895.

HARRY FOSTER BAIN, M. S., Idaho Springs, Colo. December, 1895.

RUFUS MATHER BAGG, Ph. D., Colorado College, Colorado Springs, Colo. December, 1896.

S. PRENTISS BALDWIN, Williamson Building, Cleveland, Ohio. August, 1895.

ERWIN HINCKLEY BARBOUR, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

GEORGE H. BARTON, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

FLORENCE BASCOM, Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

WILLIAM S. BAYLEY, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*GEORGE F. BECKER, Ph. D., Washington, D. C.; U. S. Geological Survey.

CHARLES E. BEECHER, Ph. D., Yale University, New Haven, Conn. May, 1889.

ROBERT BELL, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

CHARLES P. BERKEY, Ph. D., Minneapolis, Minn.; Instructor in Mineralogy, University of Minnesota. August, 1901.

SAMUEL WALKER BEYER, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

ALBERT S. BICKMORE, Ph. D., American Museum of Natural History, New York; Professor in charge Department of Public Instruction. December, 1889.

IRVING P. BISHOP, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

EMILIO BÖSE, Ph. D., Calle del Paseo Nuevo, no. 2, Mexico, D. F.; Geologist of the Instituto Geologico de Mexico. December, 1899.

*JOHN C. BRANNER, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

ALBERT PERRY BRIGHAM, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

*GARLAND C. BROADHEAD, Columbia, Mo.; Professor of Geology in the University of Missouri.

ALFRED HULSE BROOKS, B. S., Washington, D. C.,; Assistant Geologist, U. S. Geological Survey. August, 1899.

*SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa; State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., 1420 Josephine St., Denver, Colo.; Mining Engineer. May, 1889.

* T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

CLARENCE RAYMOND CLAGHORN, B. S. M. E., Vintondale, Pa. August, 1891.

* WILLIAM BULLOCK CLARK, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

JOHN MASON CLARKE, A. M., Albany, N. Y.; State Paleontologist. December, 1897.

J. MORGAN CLEMENTS, Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

COLLIER COBB, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

ARTHUR P. COLEMAN, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

GEORGE L. COLLIE, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

* THEODORE B. COMSTOCK, Los Angeles, Cal.; Mining Engineer.

* FRANCIS W. CRAGIN, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

* ALBERT R. CRANDALL, A. M., Alfred, N. Y.

ALJA ROBINSON CROOK, Ph. D., Evanston, Ill.; Professor of Mineralogy and Petrography in Northwestern University. December, 1898.

* WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Asst. Prof. of Mineralogy and Lithology in Massachusetts Inst. of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

EDGAR R. CUMINGS, A. B., Bloomington, Ind.; Instructor in Geology, Indiana University. August, 1901.

* HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

* NELSON H. DARTON, United States Geological Survey, Washington, D. C.

* WILLIAM M. DAVIS, Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

DAVID T. DAY, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

* JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 711 Walnut St., Philadelphia, Pa. Dec., 1888.

RICHARD E. DODGE, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

* EDWIN T. DUMBLE, Austin, Texas; State Geologist.

~~CLARENCE E. DUTTON, Major U. S. A., Ordnance Department, Washington, D. C. August, 1891~~.

* WILLIAM B. DWIGHT, Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; In charge of Vertebrate Paleontology, Museum of Comparative Zoölogy, Harvard University. December, 1895.

* GEORGE H. ELDRIDGE, A. B., United States Geological Survey, Washington, D. C.

ARTHUR H. ELFTMAN, Ph. D., 706 Globe Building, Minneapolis, Minn. Dec., 1898.

ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

* BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

* SAMUEL F. EMMONS, A. M, E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN; F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. FALES, Danville, Kentucky; Professor in Centre College. December, 1888.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

AUGUST F. FOERSTE, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences. December, 1899.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* PERSIFOR FRAZER, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* HOMER T. FULLER, Ph. D., Springfield, Mo.; President of Drury College.

MYRON LESLIE FULLER, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

HENRY STEWART GANE, Ph. D., 116 Market St., Chicago, Ill. December, 1896.

HENRY GANNETT, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* GROVE K. GILBERT, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

ADAM CAPEN GILL, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. GLENN, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

CHARLES H. GORDON, Ph. D., Lincoln, Neb.; Superintendent of Schools. August, 1893.

AMADEUS WILLIAM GRABAU, S. B., Columbia University, New York city; Lecturer on Paleontology. December, 1898.

ULYSSES SHERMAN GRANT, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

HERBERT E. GREGORY, Ph. D., New Haven, Conn.; Assistant Professor of Physiography, Yale University. August, 1901.

WILLIAM STUKELEY GRESLEY, 123 Green Hill, Derby, England; Mining Engineer. December, 1893.

GEORGE P. GRIMSLEY, Ph. D., Topeka, Kans.; Professor of Geology in Washburn College. August, 1895.

LEON S. GRISWOLD, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

FREDERIC P. GULLIVER, Ph. D., St. Mark's School, Southboro, Mass. August, 1895.

ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* CHRISTOPHER W. HALL, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

John B. Hastings, M. E., 20 Broad St., New York city. May, 1889.

John B. Hatcher, Ph. B., Carnegie Museum, Pittsburg, Pa. August, 1895.

* Erasmus Haworth, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

* Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

* Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

* Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, Ph. D., Madison, Wis.; Professor of Mineralogy in the University of Wisconsin. August, 1891.

* Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., N. Y. Botanical Garden, Bronx Park, New York; Instructor in Geology, Columbia University, August, 1893.

* Joseph A. Holmes, Chapel Hill, N. C.; State Geologist and Professor of Geology in University of North Carolina.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Instructor in Geology, Syracuse University. December, 1894.

* Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Assistant Curator of Geology.

* Horace C. Hovey, D. D., Newburyport, Mass.

* Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

* Alpheus Hyatt, B. S., Boston Society of Natural History, Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. Dec., 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* James F. Kemp, A. B., E M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. August, 1890.

Wilbur C. Knight, B. S., A. M., Laramie, Wyo.; Professor of Mining and Geology in the University of Wyoming. August, 1897.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Henry B. Kümmel, Ph. D., Trenton, N. J.; Assistant State Geologist. December, 1895.

* George F. Kunz, care Tiffany & Co., 15 Union Square, New York city.

George Edgar Ladd, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

ALFRED C. LANE, Ph. D., Lansing, Mich.; State Geologist of Michigan. Dec., 1889.

DANIEL W. LANGTON, Ph. D., 39 East Tenth St., New York city; Mining Engineer. December, 1889.

ANDREW C. LAWSON, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

* J. PETER LESLEY, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

FRANK LEVERETT, B. S., Ann Arbor, Mich.; Asst. U. S. Geol. Survey. Aug., 1890.

WILLIAM LIBBEY, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

WALDEMAR LINDGREN, U. S. Geological Survey, Washington, D. C. August, 1890.

ROBERT H. LOUGHRIDGE, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

THOMAS H. MACBRIDE, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

HENRY MCCALLEY, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

RICHARD G. MCCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

JAMES RIEMAN MACFARLANE, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

* W J MCGEE, Washington, D. C.; Bureau of North American Ethnology.

WILLIAM MCINNES, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

PETER MCKELLAR, Fort William, Ontario, Canada. August, 1890.

CYRUS F. MARBUT, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

VERNON F. MARSTERS, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

EDWARD B. MATHEWS, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. MELL, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

JOHN C. MERRIAM, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

* FREDERICK J. H. MERRILL, Ph. D., State Museum, Albany, N. Y.; Director of State Museum and State Geologist.

GEORGE P. MERRILL, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

ARTHUR M. MILLER, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

JAMES E. MILLS, B. S., Quincy, Plumas Co., Cal. December, 1888.

THOMAS F. MOSES, M. D., Worcester Lane, Waltham, Mass. May, 1889.

* FRANK L. NASON, A. B., West Haven, Conn.

* PETER NEFF, A. M., 361 Russell Ave., Cleveland Ohio.

FREDERICK H. NEWELL, B. S., U. S. Geol. Survey, Washington, D. C. May, 1889.

JOHN F. NEWSOM, A. M., Stanford University, Cal.; Associate Professor of Metallurgy and Mining. December, 1899.

WILLIAM H. NILES, Ph B., M. A., Cambridge, Mass. August, 1891.

WILLIAM H. NORTON, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

CHARLES J. NORWOOD, Mining Engineer; St. Bernard Coal Co., Earlington, Ky. August, 1894.

EZEQUIEL ORDONEZ, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

* AMOS O. OSBORN, Waterville, Oneida Co., N. Y.

HENRY F. OSBORN, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.

CHARLES PALACHE, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

* HORACE B. PATTON, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

FREDERICK B. PECK, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

SAMUEL L. PENFIELD, Ph. B., M. A., New Haven, Conn.; Professor of Mineralogy, Sheffield Scientific School of Yale University. December, 1899.

RICHARD A. F. PENROSE, JR., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

JOSEPH H. PERRY, 176 Highland St., Worcester, Mass. December, 1888.

* WILLIAM H. PETTEE, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

LOUIS V. PIRSSON, Ph. D., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

* JULIUS POHLMAN, M. D., University of Buffalo, Buffalo, N. Y.

JOHN BONSALL PORTER, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

* JOHN W. POWELL, Bureau of Ethnology, Washington, D. C.

JOSEPH HYDE PRATT, Ph. D., Chapel Hill, N. C.; Assistant Geologist, North Carolina Geological Survey. December, 1898.

* CHARLES S. PROSSER, M. S., Columbus, Ohio; Associate Professor of Historical Geology in Ohio State University.

* RAPHAEL PUMPELLY, U. S. Geological Survey, Dublin, N. H.

EDMUND C. QUEREAU, Ph. D., Aurora, Ill. August, 1897.

FREDERICK LESLIE RANSOME, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

HARRY FIELDING REID, Ph. D., Johns Hopkins Univ., Baltimore, Md. Dec., 1892.

WILLIAM NORTH RICE, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

CHARLES H. RICHARDSON, Ph. D., Hanover, N. H.; Instructor in Chemistry and Mineralogy, Dartmouth College. December, 1899.

HEINRICH RIES, Ph. D., Cornell University, Ithaca, N. Y.; Instructor in Economic Geology. December, 1893.

* ISRAEL C. RUSSELL, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

* JAMES M. SAFFORD, M. D., LL. D., Dallas, Texas.

ORESTES H. ST. JOHN, Raton, N. Mex. May, 1889.

* ROLLIN D. SALISBURY, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

FREDERICK W. SARDESON, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

* CHARLES SCHAEFFER, M. D., 1309 Arch St., Philadelphia, Pa.

FRANK C. SCHRADER, M. S., A. M., U. S. Geological Survey, Washington, D. C. August, 1901.

CHARLES SCHUCHERT, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

WILLIAM B. SCOTT, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

HENRY M. SEELY, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1899.

* NATHANIEL S. SHALER, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

GEORGE BURBANK SHATTUCK, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

EDWARD M. SHEPARD, A. M., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

WILL H. SHERZER, M. S., Ypsilanti, Mich.; Professor in State Normal Sch. Dec., 1890.

* FREDERICK W. SIMONDS, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

* EUGENE A. SMITH, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

FRANK CLEMES SMITH, B. S., Deadwood, S. Dak.; Mining Engineer. Dec., 1898.

GEORGE OTIS SMITH, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

* JOHN C. SMOCK, Ph. D., Trenton, N. J.; State Geologist.

CHARLES H. SMYTH, JR., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

HENRY L. SMYTH, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

ARTHUR COE SPENCER, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

* J. W. SPENCER, Ph. D., 152 Bloor St. East, Toronto, Canada.

JOSIAH E. SPURR, A. B., A. M., Constantinople, Turkey. Dec., 1894.

JOSEPH STANLEY-BROWN, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

TIMOTHY WILLIAM STANTON, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

* JOHN J. STEVENSON, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

WILLIAM J. SUTTON, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

JOSEPH A. TAFF, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

JAMES E. TALMAGE, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

RALPH S. TARR, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

WILLIAM G. TIGHT, M. S., Albuquerque, N. M.; President and Professor of Geology, University of New Mexico.. August, 1897.

* JAMES E. TODD, A. M., Vermilion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* HENRY W. TURNER, B. S., U. S. Geological Survey, San Francisco, Cal.

JOSEPH B. TYRRELL, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

JOHAN A. UDDEN, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

* WARREN UPHAM, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

* CHARLES R. VAN HISE, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.

FRANK ROBERTSON VAN HORN, Ph. D., Cleveland, Ohio; Instructor in Geology and Mineralogy, Case School of Applied Science. December, 1898.

THOMAS WAYLAND VAUGHAN, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

* ANTHONY W. VOGDES, Fort Wadsworth, Staten Island, N. Y.; Captain Fifth Artillery, U. S. Army.

* MARSHMAN E. WADSWORTH, Ph. D., State College, Pa.; Professor of Mining and Geology, Pennsylvania State College.

* CHARLES D. WALCOTT, U. S. National Museum, Washington, D. C.; Director U.S. Geological Survey.

HENRY STEPHENS WASHINGTON, Ph. D., Locust, Monmouth Co., N. J. August, 1896.

THOMAS L. WATSON, Ph. D., Granville, Ohio; Professor of Geology, Denison University. June, 1900.

WALTER H. WEED, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

STUART WELLER, B. S., Chicago, Ill. Instructor in University of Chicago. June, 1900.

LEWIS G. WESTGATE, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

THOMAS C. WESTON, Ottawa, Canada. August, 1893.

DAVID WHITE, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.

* ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

* EDWARD H. WILLIAMS, JR., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* HENRY S. WILLIAMS, Ph. D., New Haven, Conn ; Professor of Geology and Paleontology in Yale University.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

SAMUEL WENDELL WILLISTON, Ph. D., M. D., Lawrence, Kans.; Professor of Historical Geology, University of Kansas. December, 1898.

ARTHUR B. WILLMOTT, M. A., Sault Ste. Marie, Ontario, Can. December, 1899.

ALEXANDER N. WINCHELL, M. S., Butte, Mont.; Professor of Geology and Mineralogy, Montana State School of Mines. August, 1901.

* HORACE VAUGHN WINCHELL, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

* NEWTON H. WINCHELL, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

* ARTHUR WINSLOW, B. S., care of United States and British Columbia Mining Company, 104 W. 9th St., Kansas City, Mo.

JOHN E. WOLFF, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

ROBERT SIMPSON WOODWARD, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

JAY B. WOODWORTH, B. S., 24 Langdon St., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

ALBERT A. WRIGHT, Ph. D., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

* G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

WILLIAM S. YEATES, A. B., A. M., Atlanta, Ga.; State Geologist of Ga. Aug., 1894.

FELLOWS DECEASED

*** Indicates Original Fellow (see article III of Constitution)**

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1896.
*James Hall, LL. D. Died August 7, 1898.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Joseph F. James, M. S. Died March 29, 1897.
Ralph D. Lacoe. Died February 5, 1901.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Richard Owen, LL. D. Died March 24, 1890.
*Franklin Platt. Died July 24, 1900.
Charles Wachsmuth. Died February 7, 1896.
Theodore G. White, Ph. B., A. M. Died July 7, 1901.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died November 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.

Summary

Original Fellows	74
Elected Fellows	173
Membership	247
Deceased Fellows	31

INDEX TO VOLUME 12